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Vol. 36, No. 6 December, 1946

Journal of Experimental Psychology

EDITED BY

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AND 1515 MASSACHUSETTS AVE., N. W., WASHINGTON 5, D. C.

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EXPERIMENTAL INVESTIGATION OF THE RELATION OF LANGUAGE TO TRANSPOSITION BEHAVIOR IN YOUNG CHILDREN

BY MARGARET R. KUENNE

University of Wisconsin *

INTRODUCTION

The phenomenon of transposition in the discrimination behavior of animals and young children has received a considerable amount of attention from psychological theorists. The Gestalt psychologists, in particular, have made much of this ability of *Ss* to transfer a learned differential response, e.g., a response to the larger of two stimuli, to a new combination of stimulus objects differing in the same property (e.g., size), and they have cited it as conclusive evidence that the response was to the relative properties of the stimulus situation.

Relational theories of transposition, as has been pointed out by others (**5, 27**), fall into two groups. According to one type (**1, 13, 15, 20, 22**) the organism perceives the relationship between the training stimuli and employs this 'relational-perception' in responding differentially to the transposed stimulus situation. Thus, Kinnaman, the earliest investigator of this problem, wrote regarding the results in his brightness experiment with monkeys: "It would appear then that if the monkey managed to choose with measurable correctness, he very likely had a general notion of a low order which might be represented by *food-always-in-the-lighter*" (**15**, p. 143).

The second type of relational theory conceives of the organism as responding differentially to the training stimuli as a stimulus whole. The formulations of Köhler (**17, 18**), and Gulliksen and Wolfle (**5**) fall

* This article is based on a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the Iowa Child Welfare Research Station, in the Graduate College of the State University of Iowa. The writer is deeply indebted to Professor Kenneth W. Spence for his advice and assistance throughout the course of the study.

into this category. Thus, Köhler, in explaining his brightness experiments, stresses the 'togetherness' of the stimuli, recognizing that this togetherness may occur independently either as *color-wholes* or as *perceived color-relations*. He regards the two processes as distinct but their functions as similar, and so he chooses to ignore the differences. In either case, the colors (brightnesses) are assumed to attain an 'inner union' in which their role "depends not upon their absolute qualities, but upon their places in the system they compose. If their places with respect to each other are held constant, but a variation is made in their absolute quality, the Gestalt and the perceived relationship will be transposed" (**17**, p. 221). The occurrence of transposition is then regarded as evidence of such a configural response.

Köhler has made no further attempt to elaborate his theory so as to explain the occurrences of failure of transposition which have been found under a number of experimental conditions. A configuration theory more adequate in this respect is the recent one of Gulliksen and Wolfle (**5**). They conceive of the animal in the discrimination situation as responding directionally to the total stimulus configuration consisting of the stimuli varying in a single dimension and presented simultaneously in a given spatial order. Thus, in the two-choice size discrimination situation, the animal learns to respond differentially (left or right) to the two configurations, small on left and large on right, small on right and large on left. They assume, further, the operation of the law of effect and generalization of the effects of the learning on the training-stimulus configuration to similar configurations. On the basis of this theoretical schema, these writers were able to deduce a number of implications which are in agreement with existing experimental data. An outstanding exception is the failure of the theory to deduce one of the most well established experimental findings concerning transposition—the tendency for it to decrease as the distance between the training and test stimuli is increased.

Contrasting sharply with these two types of relational theories of transposition phenomena is the stimulus-response theory suggested by Spence (**23**, **24**, **25**, **26**). Based on principles derived from experimental studies of conditioning, his theory represents an extension of an earlier theoretical treatment of the nature of discrimination learning in animals. According to this latter formulation, discrimination learning is a cumulative process in which reinforcement strengthens the excitatory tendency or association of the positive stimulus cue to the response of approaching it as compared with the response of approaching the negative stimulus cue which receives only non-reinforcement, hence developing an opposing inhibitory tendency.

When the difference between the excitatory strengths of the two cue aspects is sufficiently large, so as always to be greater than any differences in the excitatory strengths of other stimulus aspects that may happen to be allied in their response-evoking action with one or another of the cue stimuli on a particular trial, the *S* will consistently respond to the positive stimulus; in other words, he will have learned.

In extending the theory to the problem of transposition, Spence assumes that the excitatory tendency to respond to the positive cue aspect generalizes to other members of the stimulus dimension according to the exponential function $E = Ae^{-cx^2}$, where X is the distance in logarithmic units between the positive stimulus and that stimulus point under consideration on the dimension. Similarly, the inhibitory tendency to respond to the negative cue aspect is assumed to generalize to other members of the stimulus dimension according to the function $I = Be^{-kx^2}$, X being the distance in logarithmic units

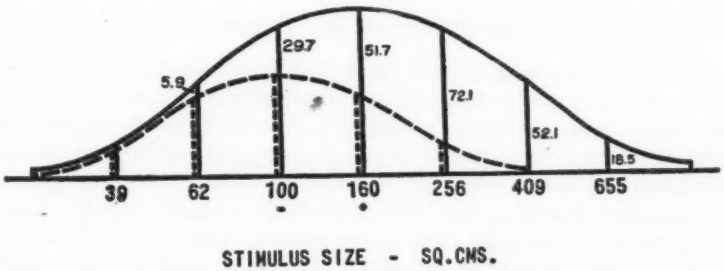

FIG. 1. Diagrammatic representation of the relations between the hypothetical generalization curves, positive and negative, after training on the stimulus combination 160(+) and 100 (−)

between the negative stimulus and that stimulus point under consideration on the dimension. The excitatory and inhibitory tendencies to respond to a stimulus cue at any point on the dimension are assumed further to summate algebraically, yielding the effective excitatory strength at that point. Which of a pair of any stimulus members of a dimension will be chosen by an organism after training on a particular pair will depend upon the magnitude of the difference in the effective excitatory strengths of the competing stimulus cues as calculated from the values of the generalization curves.

The accompanying diagram, Fig. 1, taken from one of Spence's (27) recent papers, illustrates the workings of the theory. The *S* is assumed to have been trained to choose a square of 160 sq. cm., in preference to one of 100 sq. cm. The stimulus members indicated on the base line are placed at equal intervals on a logarithmic scale,

and for each of these there is calculated the effective excitatory strength, determined by summing algebraically the excitatory and inhibitory generalization values for the given member. Comparing these hypothetical effective strengths for pairs of stimuli on the dimension, one would be led to predict that transposition will occur on pairs 256 vs. 160 and 100 vs. 62, but that transposition should fail to occur in the case of stimulus pairs farther removed from the training pair.

While insufficient knowledge as to the nature of the variation of generalization curves from individual to individual precludes the possibility of making specific deductions as to the exact results to be expected from individual *Ss* at each point on the stimulus dimension, nevertheless the theory does lead to certain more general implications which are experimentally testable. One of these, that the amount of transfer will be less the farther removed the test pair from the original training pair, is of particular importance for the present investigation.

Statement of the Problem

The present study takes its point of departure from the theoretical formulation of transposition phenomena proposed by Spence. This theory was developed in relation to the behavior of nonarticulate organisms and is assumed to represent the underlying mechanisms (variables and laws) operating in infrahuman subjects and possibly in human *Ss* prior to the advent of verbal processes. In the case of an organism possessing verbal responses, however, behavior in discrimination situations presumably becomes cued to some extent to such words as 'bigger,' 'longer,' 'brighter,' etc. Observation and phenomenological reports suggest that verbal processes dominate such behavior in the case of the human adult. The relational theories originally proposed by the early American experimenters provide excellent examples of the recognition of the role of verbal processes in the human *S*. In line with the existing tendency to anthropomorphize, these writers projected their own processes into their animal *Ss*, although they usually acknowledged that such abstractions could function only as 'more general notions,' whatever that might mean.

As a basis for an attempt to extend our understanding of discrimination behavior and the phenomenon of transposition in human *Ss*, *the working hypothesis is here adopted that the mechanisms assumed by Spence to underlie this behavior in animals are also operative in the young child, and that with the development in older children of the capacity to employ verbal responses in such behavior situations, a shift occurs to the verbal type of control.*

According to this assumption, the child who has not yet learned the terms 'bigger' or 'smaller,' or who has not yet learned to control his overt behavior by means of such verbal responses or their implicit equivalents in a size discrimination problem, would learn the discrimination in much the same way as the animal *S*. Transfer of the learned response to another set of stimuli differing from the training set only with respect to size, would depend upon the generalization of excitation and inhibition from the positive and negative members of the training pair, respectively, to these other members of the size dimension. With increasing distance on the continuum of the test stimuli from the training pair, the differential effects of generalization would be expected to decrease until a point is eventually reached at which the difference would be too small to produce a differential response to the test stimuli. Non-cue factors would then be decisive and should produce a response which, except in the case of an original size preference, would be unrelated to the size aspect of the stimuli. A group of nonverbal *S*s would, in such a case, be expected to respond in a manner consistent with original training only a chance number of times.[1]

The child whose discrimination behavior is controlled by verbalization of the cue aspect of the stimulus situation should, on the other hand, generalize equally well to all other pairs of test stimuli differing from the training stimuli in the same dimension. For example, if he learns to respond to the 'smaller' of a stimulus pair during training and is then tested on a new stimulus pair also maintaining the relationship 'smaller-larger,' it is expected that he will abstract the relationship in the new pair and respond on the basis of it to the smaller stimulus of the pair, whatever the distance of the test stimuli from the training stimuli. His choice behavior, in other words, will be controlled by some such verbal response as 'always in the smaller'.

Studies of transposition of response in children thus far reported in the literature consistently show that transposition occurs in a large proportion of cases, but they have employed only test stimuli near to the original training pair. Transposition would be expected under this condition whether the child used verbal responses effectively or not: in the first instance through generalization on a verbal basis; in the second, through generalization on a simple conditioning basis. Thus, the findings are not critical so far as the present hypothesis is concerned. Evidence for or against it can be obtained only on transposition tests with stimuli that are at a considerable distance from the training pair. This investigation attempts to provide such evidence.

[1] The size dimension has been used for illustrative purposes, but any other stimulus continuum such as brightness, weight, etc., would be equally applicable.

In the absence of a measure of the extent to which the child employs the type of verbal concepts demanded by the theory, mental age has been taken as a rough indicator of the degree to which verbal or symbolic responses control behavior. *The implications of our working hypothesis are, then, that (mentally) very young children trained in a discrimination situation and in whom, presumably, verbal mechanisms are not highly developed, will respond on the distant transposition test in a chance manner, not in a manner consistent with training, while (mentally) older children, in whom the verbal-type mechanism is presumably well established, will exhibit transposition, that is, will respond in the distant test situation in a manner consistent with the original training.* It is probable that intermediate age groups will, as groups, fall somewhere between these two extremes, for some individuals will still be in the nonverbal stage, some will have progressed to the verbal level, while still others might possibly be in a stage of transition.

Review of Previous Studies

Comparatively few transposition experiments have employed child *Ss*, and none has treated the variables under consideration in the present study, namely: 1, the relation of the choice to the distance of the two test stimuli from the training pair on the stimulus dimension, and 2, the relation of choice to verbal development. Köhler (18), Frank (3), Klüver (16) and Jackson *et al.* (12) have demonstrated the predominance in children of relative choices on critical tests with stimuli one step [2] distant from the training pair on a size, brightness, or weight dimension, even under the condition of over-training. Other transposition experiments with children (7, 8, 9, 10, 11) have employed conditions irrelevant to the present problem.

In the animal field, a number of investigators have studied the relation of transposition to the distance of the test stimuli from the training stimuli on a single dimension. Gulliksen (4) and Flory (2) working with white rats, and Klüver (16) and Spence (25) working with chimpanzees, have consistently found that, in the size dimension, as the distance between the training and test stimuli increases from one to five steps, the frequency of relative choices decreases from a significantly high toward a chance level. Kendler (14), employing hooded rats, conducted a similar experiment in the brightness dimension through four step intervals. She found a progressive decrease in the relative choice through the first three steps, but a rise or

[2] 'Step,' a term introduced by Kendler (14), refers to the distance on the stimulus dimension of the test stimuli from the training stimuli, such that the members of the test set have the same relation to the corresponding members of the training set, as the members of the training set have to each other. One step interval is represented by the distance between a training pair 10 vs. 5, for example, and a test pair 20 vs. 10.

leveling off thereafter, depending on whether training was to the brighter or duller stimulus. Thus, the findings with respect to the distance variable in transposition experiments with animals tend to be in line with the theory based on conditioning principles.

Experiment

A. Subjects

Thirty-eight children from the preschools of the University of Iowa and 18 children from the kindergarten of the Horace Mann Public School in Iowa City were *S*s in this experiment. They were selected on the basis of mental age scores within the range three to six years, and intelligence quotients of average or higher. In all, 12 who had from 140 to 630 training trials left school

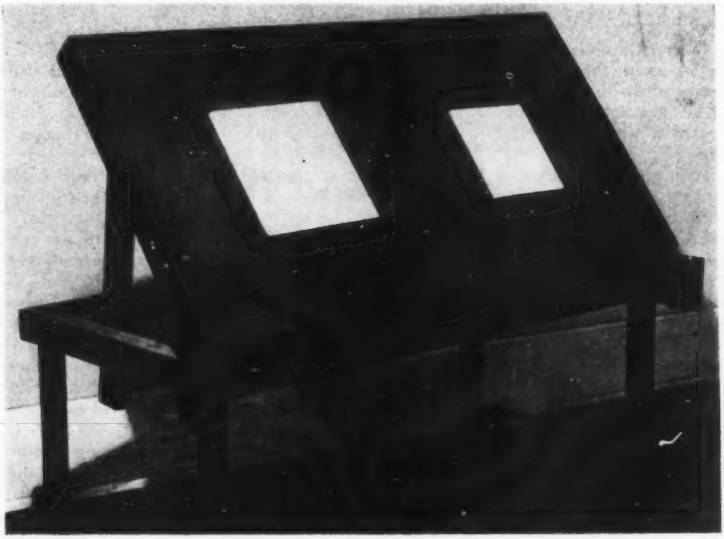

Fig. 2. Photograph of the apparatus with the training stimuli in position

before they reached the learning criterion. Those who completed the study ranged in CA at the start of the experiment from 30 to 70 months, in MA from 36 to 83 months, and in IQ from 89 to 151.

Mental age and intelligence scores were obtained for all *S*s on the New Revised Stanford-Binet Tests of Intelligence, Form L, within six months preceding the first day of training. With two exceptions, the investigator administered the tests. On the basis of the scores the children within each of the mental age levels 3, 4, 5 and 6 years, were divided into pairs matched for MA and IQ, and for sex whenever possible. One member of each pair was randomly assigned to one test group and the other automatically fell into the alternate group.

B. Apparatus

The apparatus, shown in Fig. 2, consisted of a stand 22 in. in height, on which rested a panel inclined at a 60-degree angle. Two 10-in. square openings were cut 10 in. apart in the panel, and

covered with hinged lids. Behind these openings boxes were constructed. A thin strip of metal $\frac{3}{8}$ in. wide was attached to the lower edge of the lid of each box to hold the stimuli in place. The metal extended over the inner edge of the lids and was bent slightly to form tabs for opening the boxes. Locks invisible to the *S* and manipulated from behind the apparatus were arranged so that the lid under the negative stimulus was always locked. Notched blocks of wood attached to the front legs of the table held a pressed wood screen in place between trials. A large variety of colorful toys, one of which was hidden each trial in the box on which the positive stimulus lay, served to motivate the child. The entire apparatus was painted flat black.

Stimuli were white-enameled $\frac{1}{4}$-in. pressed wood squares with the areas 2.0, 3.6, 21.0, 37.8 and 68.0 sq. in. These will be referred to by the numbers 1, 2, 5, 6 and 7, respectively. Numbers 3 and 4 are omitted to emphasize the links needed to complete the stimulus series whose successive members have areas maintaining the ratio 1.8:1 between them. A duplicate of stimulus 6, the positive training stimulus, was used for transposition tests as a control over responses on the near test to some specific characteristic (other than size) of the original training stimulus.

C. Experimental Procedure

Training series.—The procedure was identical for both experimental groups. *S*s were trained to choose the box with the smaller of the two stimuli, 6 and 7. Fig. 2 shows these stimuli in position. In the event of a correct response, the box opened and a toy was found inside, while in the event of an incorrect response, the box was found to be locked. The *S* was never permitted to try both boxes. Toys were collected in a cardboard box which the child held on his lap.

Training began on the first day with a preliminary set of two trials during which *E* demonstrated the response. Instructions, uniform for all *S*s, included no mention of the stimuli. On the first trial, the positive stimulus appeared on the left box, the negative on the right. The positions were reversed on the second trial. Following the demonstration the regular training session was begun. In no case was the preliminary series repeated. Any spontaneous verbalization of the cue aspect of the stimuli was recorded throughout the experiment.

Ten trials were presented the *S* each school day. On odd-numbered days the position of the positive stimulus for the 10 trials was LRLLRLRRLR. The order on even-numbered days was RLLRLRLRRL. Training was continued until the *S* chose the positive stimulus on at least the last nine of the 10 trials. In instances in which a child responded nine consecutive times on the basis of position, *E*, on the ninth trial, indicated the correct box, saying, "Look! This box opens!" Trials were then given with the positive stimulus on the nonpreferred side until the child chose correctly once.

If, after 450 standard training trials, the *S* showed no indication of approaching the learning criterion, he was given at the start of the next session, five to 10 trials in which no stimuli were present, followed immediately by the regular training trials. Five trials without stimuli were given after 470 and 490 trials if learning still had not occurred. After 500 trials, the daily session opened with 10 trials in which the positive stimulus was presented alone. This series was followed immediately by 10 regular trials. Single stimulus presentation was continued on alternate days until there was evidence of learning.

Test series.—Twenty-four hours after reaching the learning criterion the *S* was given a transposition test of 10 trials, during which all choices were rewarded. Group I was tested on the stimulus pair 5 vs. 6, while Group II was tested on the pair 1 vs. 2. If the child was not in school on the day after reaching the criterion, he was given training trials on his first day back. If he was able to choose the correct stimulus on five trials in five, he was given a 24-hour interval and then tested for transposition. If he failed on one of the five training trials, he was presented a total of 10 regular training trials that day and every day thereafter until he again reached the original criterion of nine consecutive correct choices in 10 trials. He was then given a 24-hour interval before the transposition series.

On the day following the first transposition series, 10 trials were presented with the training stimuli. If the child reached the original learning criterion, he was given a 24-hour interval and then presented with the other pair of test stimuli. For this test, Group I had the stimulus pair 1 vs. 2, while Group II had the pair 5 vs. 6. If, on the other hand, the child failed to reach the criterion, he was given 10 trials each day until he could reach it. As before, a transposition test was given after a 24-hour interval.

Elicitation of verbalization.—Following the final transposition test trial on the last day of the experiment, the screen was placed in position and the child was asked how he knew which box to open. If there was no response, the training blocks were placed in position, the screen was removed, and the *S* was asked how he knew which block to choose. If there was still no response he was asked how the blocks differed.

It was recognized, of course, that failure of the child to verbalize the size aspect aloud does not indicate that he also failed to verbalize internally; nor does failure to state a generalization in response to questioning indicate a similar failure during the course of the experiment. Furthermore, verbalizing at the conclusion of the experiment gives no cue as to the time the child actually formulated his generalization. On the other hand, the occurrence of spontaneous verbalization aloud is evidence of the presence of a verbal mechanism at least at that time. Verbalization in response to questioning indicates capacity for such a process and the possibility that it did occur during the learning period.

D. Results

The various data obtained on the 44 *S*s divided into four mental age levels are presented in Tables I to IV. The first column of each

TABLE I

LEARNING AND TEST DATA FOR SUBJECTS AT THE THREE-YEAR LEVEL

Subjects	CA Mos.	MA Mos.	IQ	No. Trials	No. 'Smaller' Responses in 10 Trials	
					Near Test	Far Test
Group I (*S*s given near test first)						
1	34	36	107	590	9	6
2	43	38	89	320	9	4
3	40	42	105	190	10	6
4	30	44	148	40	10	4
Group II (*S*s given far test first)						
5	37	37	100	540	7	5
6	40	42	105	170	10	5
7	39	46	119	500	10	5
Means	37.6	40.7	110.4	335.7	9.3	5.0
Medians	39	42	105	320	9.5	5.0

table identifies the *S* by number, and the next three contain data on CA, MA, and IQ, respectively, for each individual. The fifth column gives the total number of standard trials required to attain the criterion of learning in the discrimination situation. Finally, the last two columns show the number of responses consistent with the original training made in the 10 trials on the near test and the 10 trials on the far test. Each of the tables has been divided into an upper and lower part. The former includes those *S*s (Group I) who were given the near test first; the latter, those *S*s (Group II) who had the far test first. At the bottom of each table appear the

TABLE II

LEARNING AND TEST DATA FOR SUBJECTS AT THE FOUR-YEAR LEVEL

Subjects	CA Mos.	MA Mos.	IQ	No. Trials	No. 'Smaller' Responses in 10 Trials	
					Near Test	Far Test
Group I (*Ss* given near test first)						
8	43	48	112	360	9	7
9	41	53	129	40	10	5
10	59	58	98	90	1	5
11	41	58	142	400	10	10
12	45	59	131	230	10	4
13	44	59	133	170	10	10
Group II (*Ss* given far test first)						
14	52	54	104	90	10	3
15	42	56	134	190	10	6
16	37	56	151	380	0	10
17	39	58	149	176*	1	6
18	46	59	128	380	10	6
Means	44.5	56.2	128.3	227.8	7.4	6.5
Medians	43	58	131	190	10	6

* On one training day, only six trials were given for reasons beyond *E*'s control.

TABLE III

LEARNING AND TEST DATA FOR SUBJECTS AT THE FIVE-YEAR LEVEL

Subjects	CA Mos.	MA Mos.	IQ	No. Trials	No. 'Smaller' Responses in 10 Trials	
					Near Test	Far Test
Group I (*Ss* given near test first)						
19	61	60	98	290	10	10
20	64	65	102	270	10	7
21	65	65	100	50	10	8
22	68	66	97	160	10	4
23	66	70	106	110	10	2
24	62	70	113	200	10	10
Group II (*Ss* given far test first)						
25	63	65	103	200	10	7
26	64	65	102	210	10	9
27	62	66	107	30	10	10
28	67	67	100	250	10	10
29	65	70	108	310	10	8
30	63	71	113	220	10	9
Means	64.2	66.7	104.1	191.7	10	7.8
Medians	64	66	102.5	205	10	8

TABLE IV

LEARNING AND TEST DATA FOR SUBJECTS AT THE SIX-YEAR LEVEL

Subjects	CA Mos.	MA Mos.	IQ	No. Trials	No. 'Smaller' Responses in 10 Trials	
					Near Test	Far Test
Group I (*Ss* given near test first)						
31	60	72	120	50	10	10
32	67	74	111	130	10	9
33	70	75	107	130	10	10
34	61	77	126	100	10	10
35	61	78	128	190	10	10
36	67	81	121	10	10	10
37	64	83	130	50	10	10
Group II (*Ss* given far test first)						
38	63	72	115	40	10	10
39	66	73	111	60	10	10
40	68	74	109	20	10	10
41	65	75	116	10	10	10
42	67	78	117	80	10	10
43	68	80	118	10	10	10
44	63	80	127	120	10	10
Means	65.0	76.6	118.3	71.4	10	9.9
Medians	65.5	76.0	117.5	55	10	10

means and medians of these various measures for each mental age group.

Learning.—An examination of the data showing the number of trials to reach the learning criterion of nine consecutive correct choices in 10 reveals that the individual *Ss* ranged from 10 to 590 trials. There is evident a marked tendency for the low scores (fast learning) to be concentrated at the older age levels and the high scores (slow learning) to be found at the younger age levels. Both measures of central tendency for the four age groups reveal a decrease in the number of trials with increasing age, the means showing a consistent downward trend and the medians a single inversion between ages four and five. Further support for this relation between speed of learning and mental age is provided by the product-moment coefficient of correlation of $-.62$ found between these variables. For a significant relationship at the one-tenth of one percent level with this number of cases, a coefficient of only .47 is needed. Speed of learning is also highly correlated with chronological age as shown by the r of $-.55$ between these two measures.

In addition to the regular training trials, special trials ranging in number from 2 to 199 were given to eight three- and four-year-old

Ss and one five-year-old in an attempt to modify position habits. In line with the plan described in Section C, three three-year-old *Ss*—Nos. 1, 5, and 7—were given 5 to 20 trials without the stimuli present, and *Ss* 1 and 5 also received single-stimulus trials numbering 15 and 10, respectively. These data serve to add to the evidence that the problem was relatively much more difficult for the young *Ss* than for the older ones.

The majority of *Ss*, 28 in all, spontaneously commented on the size of the stimuli at some time during learning. Of these, nine mentioned the size aspect for the first time on the day they reached the criterion, or the day just preceding it, and 12 others verbalized the concept on one of these two days in addition to some earlier day or days. A number of other children talked about the 'big block' or 'little block' but never reached the learning criterion.

Relearning.—Only three *Ss* of the 44 required more than the minimum of 10 trials to reach the learning criterion the second time.[3] Two of these three, *Ss* 8 and 22, met the criterion after 20 trials. Both, it is interesting to note, were among the three *Ss* who at no time during the experiment verbalized the size aspect of the stimuli. *S* 30 took 40 trials to relearn the discrimination, but the conditions in this case were exceptional in that a period of over three weeks elapsed between the first transposition test and the start of the relearning. With no other *S* was the interval greater than four days.

Transposition tests.—The results of the near transposition test show that with very few exceptions the children tended to respond in a manner consistent with the original training, that is, to choose the smaller stimulus. Thus, if we select a score of 9 or more such responses in 10 as a significant one (a score of 9 would be expected on a chance basis only 10 times in 1024), it will be seen that there were only four *Ss* in all who did not choose the smaller stimulus a statistically significant number of times, that is, did not demonstrate transposition. One of these, *S* 5, was in the three-year-old group, while the other three, *Ss* 10, 16, and 17, were in the four-year-old group. The results for these latter three *Ss* on the near transposition test were quite different from those of the other children, their responses being predominantly (beyond chance) to the absolute stimulus cue.[4]

[3] The relearning series, it will be recalled, came at least 24 hours after the first transposition test.

[4] The results for these individuals are discussed in some detail in the original thesis, deposited in the library of the State University of Iowa. The behavior of *Ss* 10 and 16 are not necessarily contrary to the proposed theory. Both appear to have learned the discrimination on a nonverbal basis. Their responses on the near test could possibly be explained as resulting from very narrow generalization curves. Such an assumption would require that the responses on the far test be random, which is in line with the experimental results. The absolute choice of *S* 17 on the near test, after transposing on the far test, is contrary to the theoretical expectation.

The findings of the far transposition tests present a somewhat different picture from those of the near test, particularly in the case of the younger *Ss*. Thus, none of the *Ss* at the three-year-level behaved on this test in a manner consistent with original training. Rather, all seven responded to the two stimuli in more or less chance fashion, as may be seen from the data in the last column of Table I. The percent of *Ss* responding a statistically significant number of times (nine or more) to the smaller stimulus on this far test increased at each of the subsequent age levels. Thus, 27.3 percent (three *Ss*) of the four-year-old group, 50 percent (six *Ss*) of the five-year-old group, and 100 percent (14 *Ss*) of the six-year-old group chose in accord with their original training in nine or more of the 10 far test trials.

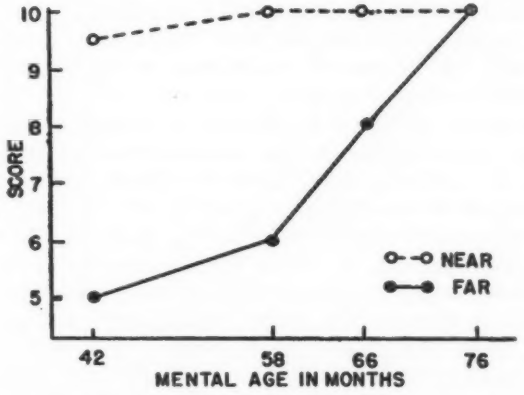

FIG. 3. Graphic representation of the relation between mental age and median scores on near and far transposition tests

The differences in the results for the two transposition tests are also revealed by the measures of central tendency included at the bottom of Tables I to IV. Fig. 3 brings together in graphic form the median near and far transposition scores made by *Ss* at various age levels. The number of transposition responses in 10 trials appears on the ordinate, while the median mental age in months for each of the four groups is plotted on the abscissa. Inspection of the almost horizontal near test curve reveals that all four age groups showed transposition to a very high degree. The far curve, on the other hand, begins at chance (5) for the youngest group and rises to 10 for the oldest group, with the intermediate age groups falling at 6 and 8.

We turn now to the consideration of the relation of these experimental facts to the theoretical formulation elaborated at the beginning of this paper. It will be recalled that the implications of this theory

were that the far transposition test would reveal significant differences between children of different age levels, whereas the near transposition test would not. In the first instance the theoretical expectation was that at some point in the age range, presumably at a very young level, the responses of the *Ss* on the far transposition test would approximate a chance result. At an older age, on the other hand, presumably when the stage of verbal abstraction and control of behavior is attained, the response of the child on this far test would be highly consistent with the direction of original training.

That the results of the experiment were in agreement with these theoretical expectations is readily apparent. The children of different age levels showed little, if any, difference in the near transposition test. In the far transposition test, however, the three-year-olds responded in a purely chance manner, while the six-year-olds showed practically 100 percent transposition. There now remains the task of ascertaining the degree of confidence we may have that these differences did not arise purely by accident.

Because of the nature of the data, for example, the skewed character of the distributions of the transposition scores and the inequality of the variances at different age levels, it was not possible to apply analysis of variance, or to apply in most instances, the usual *t*-test of significance between means. The main theoretical implications may, nevertheless, be tested for significance in the following manner. If we set up the null hypothesis with respect to differences on the two tests, near and far, for both the three- and six-year mental age groups, then our theory would require that the experimental results for the three-year-old group would lead to the rejection of the null hypothesis of no difference between the two tests at this age, while the results for the six-year mental age group would lead to acceptance of that hypothesis.

In the case of the three-year-old group, we can apply the *t*-test for differences in the means of related measures (**21**). The resulting *t* is 8.25, which far exceeds the value of 5.96 required for a significant difference at the one-tenth of one percent level. From this we would be led, as our theory demands, to reject the hypothesis that there is no difference in the results on the two tests for this age group.

Unfortunately, a similar statistical test of the differences between the near and far transposition scores for the six-year-old group cannot be made because of the almost complete lack of variability in these test scores. The nature of the results is such, however, that one can readily accept the null hypothesis that no difference exists. All *Ss* but one responded 10 times on both tests to the smaller stimulus and, in the case of the single exception, the transposition scores were 10 on the near test and 9 on the far. Thus, there are 13

cases of zero difference and a single case of a difference of 1. The probability that one would obtain on the basis of chance 13 instances of zero in 14 is extremely remote.

As was true at the six-year level, the distributions of transposition scores at the intermediate ages four and five do not justify the assumptions of normality and homogeneous variability that are necessarily made in applying the *t*-test for differences between means. There are too few *S*s to permit a chi-square test of independence on these two groups alone, but by combining the three- with the four-year group and the five- with the six-year one, the application of that test is made possible. We are interested in testing the hypothesis that there is no relationship between mental age and the occurrence of transposition (score of 9 or 10 in 10 trials) in the far test situation. The resulting chi-square, corrected for continuity by Yates' method, is 13.1, which, for one degree of freedom, exceeds the value required for significance at the one-tenth of one percent level. The hypothesis can, therefore, be rejected even if some reservation is made for the relatively small number of *S*s. Further evidence against the hypothesis of no relation between mental age and far transposition scores is furnished by the product-moment correlation of .66 obtained between these variables for the 44 *S*s This coefficient is far in excess of the value .47 required for significance at the one-tenth of one percent level.

A chi-square test of independence could not be applied to the near transposition measures to test their relationship to mental age, because the data fail to satisfy the requirement that there be a theoretical (expected) frequency of at least five in each of the cells of the contingency table. The correlational approach is likewise not applicable to these results, for the transposition scores show almost no variability. Examination of the data, however, should make one extremely hesitant about rejecting the null hypothesis of the relation between mental age and near transposition.[5]

Verbalization.—An analysis of the recorded verbalizations of the stimulus cue suggested the classification of the *S*s into four mutually exclusive categories—A, B, C and D. A includes those *S*s who at no time, either spontaneously or in response to questioning, verbalized the size aspect. In category B are those who did spontaneously

[5] Analysis of transposition scores based on only the first test trial gave results which corroborate those for 10 test trials. No significant differences were found between the different mental age groups on the near transposition test, whereas the percent of *S*s who transposed on the far test increased from 14.3 percent for the three-year-old group to 100 percent for the six-year-olds. The four- and five-year-old groups fell in between these values, with 72.7 of the former and 86.7 percent of the latter showing transposition. Application of the chi-square test of independence permits one to reject, at a confidence level between two and five percent, the hypothesis of no difference in the percent of transposition for the four groups.

mention the size variable at least once at any time during the experiment, but who failed to state the relation of size to the success or failure of choice behavior. Typical verbalizations of *Ss* in this group are: "This one is big and this one is little." "What a nice little block!" "This time I'll take the big one." *Ss* in the third class, *C*, verbalized the general principle of solution, but only in response to questioning at the conclusion of the experiment. Many of these individuals also mentioned the size of the stimuli during the training or transposition trials, but in no instance did they express generalizations at that time. Examples of replies judged as adequate generalizations are: "It's (toy) always in the little one," or "The big one doesn't open." Category D includes those children who verbally generalized with respect to the size aspect of the stimuli at some time prior to the routine questioning at the conclusion of the experiment. All except three of these *Ss* repeated the principle in reply to the experimenter's questions following the last 10 trials.

The number and percent of *Ss* at each age level who fall in the four verbalization categories are shown in Table V. It is apparent

TABLE V

NUMBER AND PERCENT OF SUBJECTS AT EACH AGE LEVEL IN THE FOUR VERBALIZATION CATEGORIES

Category	Mental Age							
	3		4		5		6	
	N	%	*N*	%	*N*	%	*N*	%
A	0	0	2	18.2	1	8.3	0	0
B	7	100.0	2	18.2	1	8.3	0	0
C	0	0	4	36.4	5	41.7	5	35.7
D	0	0	3	27.3	5	41.7	9	64.3

that the three- and four-year-old children tend to be in the non-generalizing groups (A and B) while the five- and six-year-old children are predominantly in the generalizing ones. A chi-square test of the null hypothesis of no relationship between mental age and classification in the combined A-B or combined C-D categories yields a corrected chi-square of 12.22, permitting the rejection of the hypothesis at the one-tenth of one percent level of confidence. This result lends support to our proposed use of mental age as an indicator of the ability to make verbal generalizations in such situations.

Table VI indicates the median transposition scores in 10 trials for *Ss* in the four verbalization categories, and the median number of trials to learn the discrimination originally. It is evident that *Ss*

who failed to verbalize the size aspect of the stimuli explicitly, or who merely noted the size without stating the relationship of the size aspect to the solution of the problem, behaved differently on the far transposition test from *Ss* who did formulate and state the relationship. On the near test, responses were similar from group to group.

It is possible to test the significance of the apparent relationship by using the chi-square test of independence. The obtained corrected chi-square of 18.37 permits us to reject at the one-tenth of one percent level the hypothesis of no relationship between the occurrence of transposition (a score of 9 or 10 in 10 trials) in the far test and the tendency to verbalize the solution of the discrimination problem. As in previous applications of this test, a chi-square of only 10.83 is needed for significance at this level for one degree of freedom. The

TABLE VI

MEDIAN TRANSPOSITION SCORES FOR SUBJECTS IN THE FOUR VERBALIZATION CATEGORIES

Category	*N*	Median Trials	Median Transposition Responses (10 trials)	
			Near Test	Far Test
A	3	176.0	9.0	6.0
B	10	250.0	10.0	5.0
C	14	100.0	10.0	10.0
D	17	130.0	10.0	10.0

chi-square test is not applicable to the near transposition data for the reason before discussed, of too small theoretical frequencies in the non-transposing categories. There seems to be no occasion for doubting, however, that the null hypothesis is tenable for the relation between near transposition and tendency to verbalize the principle.

Analysis of individual data with respect to the relation of verbalization to the phenomenon of transposition suggests the possibility that there are several verbal stages. There appears to be one stage in which the child verbally identifies the stimuli as 'little' and 'big,' but he fails to verbalize the relation of size to the success or failure of his choice responses. This occurred predominantly in the younger *Ss* and was associated in every case with chance performance on the far transposition test series. There is another stage—presumably a later one because of its much greater incidence in older *Ss*—in which the child states aloud or to himself that the little stimulus always leads to success and the big one to failure. The occurrence out loud of such verbal behavior in the learning or transposition series invariably was followed by transposition on the far test, regardless of the mental age of the child. In contrast, 43 percent of those who

made such verbalizations only upon questioning at the conclusion of the experiment transposed on the far series with this consistency. In the case of three *Ss* who had failed to transpose in the far test and a few seconds later, upon questioning, verbalized the principle, there seemed to be no apparent recognition of the discrepancy between this verbal formulation of the solution and their failure to act in a manner consistent with it in the immediately preceding test trials.

While the data on verbalization are not sufficiently clear-cut to permit any definite conclusions, there is, however, the suggestion that there are at least two developmental stages so far as the relation of verbal responses to overt choice behavior is concerned. In the first, the child is able to make differential verbal responses to appropriate aspects of the situation, but this verbalization does not control or influence his overt choice behavior. Later, such verbalizations gain control and dominate choice behavior.

Summary and Conclusions

Taking its point of departure from a theoretical formulation of discrimination learning based on the findings of conditioning experiments, this study hypothesizes that the simple mechanisms mediating transposition of response in infrahuman organisms are identical with those responsible for similar behavior in children in the preverbal stage of development. With the acquisition of verbal processes, however, and the transition to behavior dominated by such processes, it is hypothesized that the child's responses in the discrimination-learning situation become keyed to words relating to the cue aspect of the stimuli. Implications of this theory are that the preverbal child, like the animal *S*, will transpose consistently on test stimuli near on the dimension to the training pair, but will show only chance response on transposition tests with distant stimuli. The verbal child, on the other hand, would be expected to show transposition on both far and near stimulus tests.

As an empirical test of the proposed hypothesis, an experiment was conducted in which mental age was used as a rough indicator of verbal level. *Ss* were 44 Iowa City preschool and kindergarten children distributed over the mental age range three to six years and divided into two matched groups at each year level. Both groups were trained to select the smaller of a pair of squares whose areas were 37.8 and 68.0 sq. in. They were tested in counter-balanced order after learning, with two pairs of still smaller stimuli (21.0 vs. 37.8 sq. in., and 2.0 vs. 3.6 sq. in.). All spontaneous verbalizations of the size aspect of the stimuli were recorded throughout the experi-

ment, and attempts were made at the conclusion, through questioning, to elicit verbalization of the general principle of solution.

Analysis of the results revealed a highly significant relationship between mental age and the occurrence of far transposition, and a low relationship between mental age and near transposition. The median number of responses on the far transposition test increased with age from 50 percent at mental age three years to 100 percent at six years. The corresponding value for the near transposition test was 90 percent or above at all four age levels.

With regard to verbalization, *S*s tended to fall into four categories: 1, failure to verbalize the size aspect of the problem; 2, verbal identification of the size difference between the stimuli without explicit association of size with the success or failure of choice behavior; 3, verbalization of the principle of solution in response to questioning at the conclusion of the experiment; and 4, verbalization of the principle spontaneously during training or transposition trials. *S*s in the first two categories were significantly younger in mental age than those in the last two. No *S* in the first two categories transposed on the far test, while 73 percent of the individuals in the last two categories transposed. Analysis of the individual data suggests the possibility of two developmental stages so far as the relation of verbal responses to overt choice behavior is concerned.

On the whole, the experimental results were found to be in close accord with the proposed hypothesis.

(Manuscript received January 19, 1946)

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AN EXPERIMENTAL TEST OF THE SIGN-GESTALT THEORY OF TRIAL AND ERROR LEARNING *

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INTRODUCTION

One of the issues on which learning theorists have been most sharply divided has been the question of the roles played by motivation and reward in the process of learning or acquisition of new forms of behavior. On the one hand, we find psychologists (**4**, **10**) who emphasize what has variously been called the *principle of reinforcement*, or law of effect. According to this group, learning requires the presence or operation of a motivating state (need, drive, purpose, tension, etc.), and the occurrence of some sort of reinforcing state of affairs variously described as need satiation, reduction in drive level, tension reduction, pleasure, success, satisfactory after-effect, etc.

On the other hand, another group of psychologists (**2**, **11**, **12**) have taken a quite opposite view and have denied, in one way or another, the necessity of assuming that goal-attainment or reinforcement is responsible for bringing about the hypothetical changes within the organism that are assumed to underlie the changed or learned behavior. According to this group, association by contiguity or sequence in experience is the primary principle governing such events.

The experiment described in this report was designed primarily to investigate the sign-gestalt (non-reinforcement) theory of trial-and-error learning originally put forward by Tolman (**11**) and more recently supported by Leeper (**7**) and White (**13**). This theory vigorously opposes the viewpoint of the reinforcement group, and offers instead a picture of learning in terms of the formation of hypothetical changes which develop independent of such motivational and goal events. Tolman calls these hypothetical changes 'sign-gestalt-expectations' or cognitions, and as such they constitute, along with motivation, one of his class of intervening or theoretical variables determining behavior. A sign-gestalt expectation, according to Tolman, is a hypothetical set or bit of knowledge to the effect that certain stimuli (called signs) present in the stimulus field will, if responded

* This is the first of a number of studies on the motivational-reward conditions of learning which were carried out in the Psychological Laboratory at the State University of Iowa in the years 1939–1942. R. L. served as experimenter and K. W. S. is responsible for the report in its present form.

to in a certain manner, be succeeded by certain other stimulus events (called significates). The learning or acquisition of these sign-significate expectations arises, this theory states, as a mere consequence of the experiencing in sequential pattern the sign, the particular response, and the significate.

The experimental findings of the so-called latent learning studies, a large number of which have been carried out in his own laboratory, are mainly responsible for the position that Tolman has taken on the relation of motivation and reward to learning. The law of effect, according to Tolman, should be looked upon as a law of performance rather than a law of learning. Differential reward values among significates do make for a difference in the performance of the organism at any moment, but they play little or no part in learning *per se*, i.e., the formation of the expectation-sets.

Turning more specifically to the trial-and-error situation, Tolman describes this kind of learning as consisting in the formation of all the alternative sign-gestalt-expectations involved in the situation. That is, the organism learns what each of the initially alternative responses leads on to, or "what leads to what." Thus the theory affirms that the *S* learns that problemsituation (S_A), responded to by response R_1, leads to the resultant significate S_1; responded to by R_2, leads to the significate S_2; and so on. In effect, the *S* learns by trying out all the responses the total array of alternative sign-significate relations. The strength (or possibly clearness) of these cognitions depends, according to the theory, on the frequency and recency with which they have been experienced. Once clearly established, they make it possible for the organism to respond appropriately to the motivational conditions of the moment. If there is a need for S_1, response R_1 will occur, but if the need is for S_2, then response R_2 will take place, and so on.

More recently Leeper (7) has subscribed wholeheartedly to Tolman's view and has cited the results of his own study (6), and one by Hull (3), in support of it. These experiments tested whether rats were capable of acquiring differential spatial reactions based solely on internal conditions. The *S*s were required to learn to take one of two alternative paths when hungry and the other when thirsty. Upon finding that his animals learned this discrimination much more readily than Hull's, Leeper attributed the difference to the fact that when his *S*s made an incorrect response, i.e., took the path which led to the object for which they were not motivated, they found the non-desired object in the goal box, whereas Hull's animals were prevented from entering the goal box, and therefore were unable to perceive the incorrect goal object. According to Leeper, the incorrect runs resulted in the rat's learning where the goal material not desired on

that day was to be found, and with the motivation changed on the following days that learning was available for use. Leeper writes:

> It would seem therefore, that the rats must learn almost as much from their incorrect responses as they do from their correct responses, and it would seem also that this learning does not consist in "having the connections that led to that response stamped out" because there had been failure to secure reward, but consists rather in learning the nature of the situation to which the response led (6, p. 37).

Statement of Problem

The design of the present experiment attempted to translate the theoretical representation of simple trial-and-error learning given by Tolman, into a concrete experimental situation. Accordingly, a simple Y-choice maze was arranged as shown in Fig. 2 (the middle alley being closed off). In such a situation, if food is present in one of the goal boxes (e.g., left) and water in the other (e.g., right), then experience in this situation should lead to the learning by the animal of the two sign-gestalt expectations; one, that response to the left alley sign leads to food $S(S_L)—R_L—S_F$, and the other, that choice of the right alley sign leads to water $S(S_R)—R_R—S_W$. So far as has been specified by Tolman and Leeper, it does not matter what motivational state the S may be in when it receives these experiences. Therefore, in the above situation, an animal in need of water, but satiated for food, would presumably learn both of the afore-mentioned sign-gestalt-expectations even though it would not react by eating the food in the left box.

Motivated for water, and with no hunger drive, the animal would be expected, of course, to choose the alley leading to water. But this occurs, according to Tolman's view, not because this response has been made stronger than the competing one, as a reinforcement theorist would say, but merely because at the time of the choice, the animal is motivated for the water and has learned which path leads to water. If the motivational state were reversed, the animal would respond by taking the left pathway to food. Motivation is a determiner, along with cognition, of the response; it plays no role in the actual learning, i.e., the formation of the sign-gestalt expectations.

The present experiment was performed, then, to test the implications of this Tolman-Leeper theoretical picture. Would a group of white rats which had been given experience in the above type of maze situation immediately take the path leading to food when the motivation was shifted from thirst to hunger? Or would the *Ss* continue to respond predominantly to the water alley as the reinforcement theory would predict, because this response had been strengthened by the reinforcements it had received?

A second group of rats was also run in the same maze situation, except that the goal box which had contained food in the case of the

first group was now left empty. When motivation was shifted from thirst to hunger, this group (Group O) should presumably not be expected to abandon the water alley for the food alley so readily as the *S*s of the first group (F). Furthermore, if now given the problem of learning, under hunger motivation, to take the left alley in order to find food, group F should be demonstrably superior to Group O, as it would have the advantage of having already acquired the cognition or sign-gestalt-expectation that "S_L leads, if responded to by entering, to S_{Food}."

Experimental Procedure

Subjects

The *S*s, 20 white rats from the colony maintained by the psychology department, were divided into two equal groups of 10. There was an approximately equal distribution of *S*s with respect to sex and age in the two experimental groups. Ages ranged at the beginning of the preliminary training from 120 to 150 days.

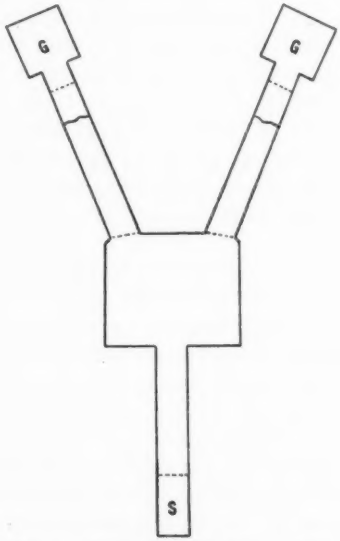

Fig. 1. Ground plan of the apparatus

Apparatus

The apparatus was a simple type Y-maze (Fig. 1) with a relatively large area at the choice point, and an adjustable jump at the entrance to each of the two alleys. The whole maze was painted a flat black and covered with ½ inch wire mesh. The dimensions were as follows: the starting alley was 7½ in. high, 5½ in. wide and 34 in. long. The choice section or decision area was 25 in. wide and 21⅜ in. long, with the entrances to the choice alleys arranged on an arc of 23 degrees. During the main part of the experiment the jump to the alleys was two in. The choice alleys were of the same construction as the starting alley, except they were 33 in. long. The detachable end or goal boxes were 12 in. by 12 in. One of the goal boxes was fitted with a water bottle similar to the type used in the living cages of the animals, the other had a sliding food tray in the floor which could be manipulated as a drawer.

There were five vertically sliding doors in the apparatus, all of which were manipulated by the *E* from behind a one-way screen centered behind the two end boxes. One door was 11 in. from the beginning of the starting alley, making a small, narrow starting box; two doors were placed at the entrance to the choice alleys; and the other two doors were 4½ in. from the end boxes, making it impossible for the animals to see what was present in the goal boxes prior to its choice.

The floor at the entrance to the left choice alley was covered with fine wire screening, while the entrance to the right alley was covered with coarse wire screening. The purpose was to emphasize the respective stimulus cues (signs) and thereby facilitate discrimination.

Preliminary training

The preliminary training in the maze involved a three-day period.

Day 1—Adjustment to the apparatus. Each *S* was placed in the beginning section of the maze and was permitted to explore freely for 20 min. Neither food nor water was present in the maze. All doors were raised and the jump gap was closed to about ½ in.

Days 2 and 3—Test for position habit. On each of the two succeeding days each *S* was given four runs with no food or water in the maze. The first two trials were 'free runs' (i.e., both choice alleys were open) and the second two trials were 'forced runs' (i.e., with only one of the choice alleys open). The purpose of the latter two trials was to insure equal number of experiences in both alleys. On the basis of these four free trials and observations of the behavior on the forced runs, the two experimental groups were selected so as to have an equal number of *S*s with strong right, weak right, strong left, weak left, and no position preferences.

Learning series involving thirst motivation

During the following 12 days, each *S* was given five trials per day, each trial being separated by from three to five min. The animals in both groups were motivated for water and satiated for food. The thirst drive was a function of 18 hours of water deprivation. Satiation for food was produced by having large pellets (approximately eight gm.) of Purina Dog Chow constantly in the living cages. Prior to their daily trials, small pellets (approximately .15 gm.) of Purina Dog Chow were made available to the *S*s. This appeared to have the desired effect of satiating the animals for the larger pellets, for no *S*s attempted to eat food in the goal box. For one group of animals (Group F) the right alley led, during these 12 training days, to water and the left alley to food. For the other group (Group 0) the right alley also led to water but the left alley led to an empty goal box. In the actual conduct of the experiment the *S*s were run as one group, with the status of the left goal box altered between trials, as determined by whether the next animal to be run was a member of Group F or Group O.

In order to insure that all animals would have ample opportunity to experience entering the left alley and finding the goal box containing food (Group F) or the empty goal box (Group 0), a number of forced runs were distributed among the five trials given each day, so that at least two trials and not more than three were to the non-water side. To obviate the danger of setting up a learning situation in which a forced run (only one door opened) always resulted in going to the same alley, at least one of the forced runs each day was to the water side. In each set of five trials there were two free runs and three forced runs. The sequence of forced and free runs was varied each day.

All *S*s promptly learned to go directly to the water orifice and start to drink. After three to five sec. of drinking they were returned to the individual carrying cages. The thirst drive remained largely unabated during the five daily trials. Each animal was given 10 to 15 sec. of exploration in the food or empty box when it went down the left alley. In most cases where the food pellets were present, the animals either smelled them or moved them with some part of their body but in no instance did any eating take place.

No retracing was allowed in the maze. When the animal made its choice by crossing the short jump (two in.) into either the right or left alley, the door was lowered behind it so that its movement was restricted to going towards the goal box. Re-entering the choice alley from the goal box was also prevented by lowering the door between them.

Learning series involving hunger motivation

On the day following the completion of this learning series, all animals were run in the maze while motivated for food and satiated for water. Hunger was produced by deprivation of food

for 24 hours, while the thirst drive was satiated by having the water bottle constantly in the living cage and also by placing water-filled pans in the cage shortly before the daily trials. The effectiveness of this procedure was revealed by the failure of any of the *S*s to drink when in the water box.

Throughout all the trials of this second learning series, food was available in the left goal box for both the 'Food' and 'Zero' groups. Ten sec. of eating were allowed on each successful trial. Five free trials were given daily with no retracing permitted. This procedure was continued daily until the criterion of 9 out of 10 successive choices of the food alley was reached.

Results

Acquisition of response to water alley

The development of the preference for the alley leading to water while under thirst motivation is shown in Table I. The data represent the number of choices of the right (water) alley by the two groups of *S*s in the two free choice trials occurring daily. It is evident from this table that the preference is fairly well established in both

TABLE I

Acquisition of Right (Water) Alley Preference under Thirst Motivation

	Number of Correct Responses				
Day	Group F	Group O	Day	Group F	Group O
1	11	12	7	20	19
2	13	17	8	20	20
3	17	15	9	20	19
4	19	20	10	20	20
5	18	20	11	20	20
6	20	19	12	20	20

groups by the fourth day, or after an average of only 7.1 experiences on the water alley in the case of Group F and 7.4 experiences in the case of Group O.[1] It is also apparent that there is little evidence of any difference in the rate of learning of the two groups. In terms of errors (choices of the left alley), Group O made an average 1.9 errors, while Group F had a mean of 2.2 errors in the 12-day period.

Effects of shift of motivation from thirst to hunger

It is readily apparent that by the end of the first learning period the *S*s of Group F had experienced the left alley sequence (S_L–S_{Food}) a considerably greater number of times (approximately 26 trials) than was necessary to learn to choose correctly the right water alley. Presumably, according to the Tolman-Leeper theory, these *S*s should now be expected to 'know' that the left alley led to food, and if now

[1] Group F averaged 4.1 responses and Group O, 4.4 responses to the right alley on the first three days of learning. Adding the forced trial given each day to this alley provides the values 7.1 and 7.4.

placed in the maze while motivated for food and satiated for water, they should be expected to take the left alley instead of the right.

The results on the first trial run under hunger motivation were entirely contrary to this theoretical expectation, for every one of the 10 *Ss* of Group F continued to take the alley leading to water. The *Ss* of Group O also responded in the same fashion, all 10 going down the right (water) alley.

A comparison of the times taken to reach the goal box on the last day of thirst motivation and first trial of hunger motivation revealed only a slight increase: from 4.0 to 5.1 sec., on the average, in Group O, and from 6.0 to 7.0 sec. in the case of Group F. Neither difference, however, is statistically significant.

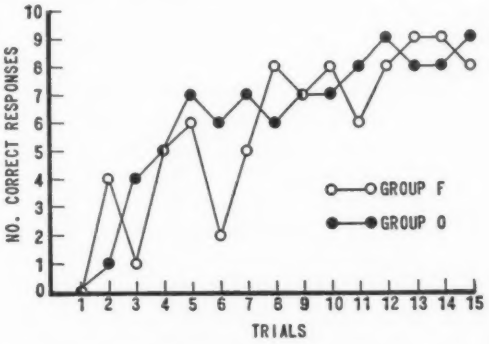

FIG. 2. Learning curves for group F and O under hunger motivation

Acquisition of response to food alley

In order to provide a further and possibly more sensitive test of the Tolman-Leeper theory, it will be recalled that the two groups were next required to learn to go to the food (left) side under hunger motivation. Even if they did not shift on the first hunger trial, the *Ss* of Group F might have been expected to learn to take the left alley for food more readily than Group O *Ss*. If the former had learned anything at all about the location of food in the original learning problem, it should have given them an advantage over the 'zero' *Ss* in this new problem.

An examination of Fig. 2, which presents the learning curves of the two groups for the first 15 trials, reveals little or no difference in the rates of learning of the two groups. Actually, in terms of the mean number of trials to attain a criterion of four correct (food) responses in one day, Group O required fewer trials (5.8) than Group F (7.5). The difference, however, is not a significant one.

Discussion of Results

The question whether the results of a particular experimental situation are or are not in accord with a theoretical formulation or system is not as simple a matter as is sometimes thought. Even when the theory is formulated in precise mathematical terms which make possible the logical derivation of very specific experimental implications, a question may nevertheless arise as to whether the particular experimental situation is an instance of the class of situations to which the theory refers. There are a number of different reasons for this difficulty. For example, it is not always possible to control variables which are known to influence the observable phenomenon, but which for various reasons have been left unconsidered in the theory. Or, again, as yet unknown variables may be operating to complicate the experimental situation. Still another instance, and one which is especially bothersome in the case of a young, undeveloped science, is the unavoidable indefiniteness that often characterizes the specification, particularly the delimitation, of the operations defining the concept employed. As an example of this last difficulty is the question as to whether in the definition of such a concept as 'cognition' as some function of the number of previous experiences or trials in the situation, a trial is to mean only a free trial or is also to include a forced trial.

These difficulties are multiplied many times over when the theoretical formulation is not specified in terms of precise mathematical equations, but is stated, as Tolman's typically is, in terms of some unknown functions. Thus, in his discussions of simple trial-and-error learning (**8**) Tolman postulates that the behavior measure is *some* function of hypothetical cognitive and motivational states which in turn are defined as *some* functions respectively of the number of experiences (trials) with the environmental situation and the time of deprivation of some goal object, e.g., water or food. But, characteristically, the nature of none of these functions is either stated or suggested. Thus, in the case of the single choice maze used in the present experiment, these assumptions would be stated as follows:

$$B = f(C_{l-f}, C_{r-w}, M_w, M_f), \qquad C_{l-f} = f(N_{l-f}),$$
$$C_{r-w} = f(N_{r-w}), \qquad M_w = f(T_w), \qquad M_f = f(T_f),$$

where B = behavior, C_{l-f} = cognition that left alley leads to food, C_{r-w} = cognition that right alley leads to water, M_w = motivation for water, M_f = motivation for food, N_{l-f} = number experiences left alley, N_{r-w} = number experiences right alley, T_w = time deprivation of water, T_f = time deprivation of food.

At best this formulation represents only the barest outline of an

adequate theory of such learning. It makes a guess as to what the relevant variables in learning are, but makes no attempt to specify the nature of their interaction. Instead, then, of making precise deductions from a set of specific equations, Tolman, somewhat intuitively, makes the simple assumption that the behavior of the animal (i.e., whether to the water or food alley) will depend upon its momentary motivation, *provided it has the appropriate cognitions as to what significate* (*food or water*) *each alley* (*sign*) *leads to.* The important part of Tolman's theorizing lies in his definition of the experimental conditions (variables) that govern the acquisition of the cognitions. Contiguity in experience of the sign, response, and significate is the essential and sufficient condition for learning. It is this guess as to the manner of defining the variables determining the development of 'cognitions' that is at stake in this experiment.

The result of our experiment would seem to cast serious doubt upon Tolman's specification of the variables determining the acquisition of 'cognitions,' and suggests that he needs to modify it in some manner. There is no necessity, of course, that Tolman abandon his anti-reinforcement position. Thus, he might redefine cognition in terms of the contiguity of the sign experience and the significate experience of need satisfaction (water alley) or non-need satisfaction (food or zero alley). In other words, the cues at the entrance of the right alley might serve merely to signify subsequent need satisfaction, whereas the left alley comes to signify a subsequent failure of need satisfaction. Lacking specification of the nature of the need satisfaction, change in motivation would not lead to a change in behavior. The *S* would thus continue to take the water alley because it signified need satisfaction.

Or again, Tolman might object that the forced trials are not comparable to the free trials, and that in reality the *S*s had only two cognition-developing trials to the food side. However, there is considerable evidence from other experiments to show that cognitions are established in such forced trials when rewards are operating (1, 9).

Turning now to a brief examination of the results of the experiment from the point of view of a stimulus-response reinforcement theory we may take Hull's recent formulation (4, 5) as an example. According to this theory two competing response tendencies are involved, as follows:

The response on the test trial will depend upon the relative strength of these tendencies, according to the following function: $R_{(\text{prob. } R)} = \int_{-\infty}^{r} \phi(t)dt$, where $r = \frac{\bar{E}_R - \bar{E}_L}{K}$, ϕt = standard probability function, E_R = excitatory potential of R_R, E_L = excitatory potential of R_L, K = empirical constant.

The values of these excitatory potentials, E_R and E_L, are in turn assumed to be functions of an intervening variable, D, and a further hypothesized variable, H, representing the learning factor. Thus: $E = f(D) \times f(H)$.

The D variable is assumed to be a kind of general drive state which is dependent upon the status (intensity) of more specific drives, e.g., hunger and thirst. For the purpose of the present experiment we need only assume that the amount or strength of this hypothetical D variable is approximately the same under the hunger and thirst conditions and hence that it is a constant in the experiment.

Habit strength (H) is defined as a positive function of a number of experimental variables only one of which (number of reinforced trials) was varied in the present experiment. Thus

$$H_R = f(N_R),$$
$$H_L = f(N_L).$$

As $N_R > N_L$ (N_L = O), the habit strength of the right response will be greater at the completion of the first learning period than that for the left response, i.e., $H_R > H_L$. It follows that $E_R > E_L$, from which the further implication may be drawn that the probability of occurrence of R_R on the first trial following shift of motivation to hunger will be greater than .50. This implication is obviously supported by the experimental results.

While Hull makes more specific postulates with respect to the above functions (e.g., that H_R is an exponential function of N, etc.), absence of independent knowledge as to the values of the parameters in his equations precludes a more precise prediction in the case of the present experiment than that given above.[2] At the present stage of development, confirmation of Hull's theorizing is limited primarily to such matters as the predicted shapes or forms of curves rather

[2] This oversimplified treatment of Hull's theory is deficient in several other respects. Thus, the effect of non-reinforcement of the response to the left (food) alley during the first learning period is omitted; nor is any consideration given to the effect of changing the internal drive stimulation on shift of the motivational state. The former would be dealt with by Hull under the concept of inhibition, and the latter under the principle of afferent neural interaction. The omission is not serious, however, for inclusion of these two factors would not alter the very crude implication drawn from the theory—namely, that $R_{\text{prob. } R} > .50$.

than particular response values corresponding to particular sets of values of the experimental variables.[3]

Even so, it should be noted that Hull's theorizing is much more advanced than Tolman's, in that he has actually formulated an explicit hypothesis as to how D and H interact to determine E, and how the empirical response measure, R, is related to the difference between the hypothetical, competing E values, etc. The specification of these interrelations among the intervening and empirical variables makes possible the derivation of the experimental implication referred to above by means of strict logic. Such is not the case in Tolman's theorizing, although as White (13, p. 171) has pointed out, it is quite possible to make the necessary assumptions within the framework of Tolman's concepts. Thus, White went at least one step further than Tolman and suggested, in effect, that $B = f(M_f \times C_{l-f})$. However, this assumption still leaves quite indeterminate the relation of the empirical measure, B, to the product of the two hypothetical variables. Any actual prediction as to the percentage of responses to the left or right path from such an assumption is still more a matter of intuition than logic. It may or may not be significant that White's prediction as to the results of the present experiment on the basis of his elaboration of the Tolman theory was entirely in error.[4]

Summary

The present investigation attempted to arrange an experimental test of Tolman's sign-gestalt (non-reinforcement) theory of trial-and-error learning. The *S*s, 20 white rats, were given 12 days of experience under thirst motivation in a simple Y-maze in which one path led to water and the other to an empty box for half of the *S*s (Group O) and food in the case of the other half (Group F). The experimental test consisted in observing the performance of the *S*s under hunger motivation. On the first trial under hunger motivation, all *S*s continued to go down the water alley. Furthermore, com-

[3] The attainment of this latter stage of development in Hull's theorizing must await the results of experimental studies with given strains of *S*s and comparable motivational and reinforcement conditions in order to ascertain whether the empirical curves fitting *different learning situations* will exhibit the same, i.e., constant, values for the parameters of the equations. The discovery of such constants under a variety of experimental situations marks a most important stage in the development of more general laws of a set of phenomena, one which no area of psychology has as yet reached.

[4] It is very probable that most readers would agree as to the implication of Tolman's theory for the present experiment without the necessity of making the logical derivation so explicit. We have belabored the point here because White, attempting to follow the example of Hull, believed he was employing rigorous logic in his exposition. The missing step in the derivation, if made explicit, would probably be something like the following: $R_{\text{prob. } L} > R_{\text{prob. } R}$, if or when $(M_f \times C_{l-f}) > (M_w \times C_{r-w})$.

parison of the two groups (O, F) in learning to go to the left alley for food showed no difference.

The results are interpreted as being in disagreement with the Tolman-Leeper theory and as supporting the stimulus-response reinforcement theory of trial-and-error learning. The difficulties encountered in the testing of the two theories are discussed at some length.

(Manuscript received January 19, 1946)

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ON THE BEHAVIOR OF THE LUMBO-SPINAL DOG

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Unless one has actually worked with spinal animals, he is not likely to possess an adequate conception of the complex and coordinated responses which it is possible for them to make. Sherrington and his associates (**4, 9, 10, 11**) have described at least 15 different reactions in spinal preparations, including such comprehensive and elaborate acts as the shaking of the entire body as if to shake off water, and the making of alternating walking movements with the hind legs. Modes of locomotion in the spinal dog have more recently been discussed by Cate (**2**); and responses of greater specificity which change with the cutting of certain of the spinal roots have been noted by Shurrager and Culler (**12**). Considered as a whole, the activity of which these 'paralyzed' organisms are capable is little short of remarkable.

Problem and Method

It is the object of the present paper to examine the behavior of the spinal animal from the point of view of the psychologist. The observations reported were obtained from six laboratory dogs whose spinal cords were completely sectioned between the first and the third lumbar roots. These should be of especial interest, because—since the lesion was well down in the cord—the spinal segment was smaller than that usually studied, and the resulting activity would be expected to be more limited. One of the *S*s was an acute preparation, and the other five were chronic specimens which were maintained for some weeks following the transection.

Surgical technique.—The operative procedure was as follows. Under full surgical anesthesia, the skin was incised for approximately three in. over the first and second, or the second and third, lumbar vertebrae. The muscle tissues were separated and the spinous and transverse processes removed with rongeurs. Entrance to the spinal canal was accomplished by means of a dental burr, and the opening was subsequently enlarged with rongeurs. The cord was exposed for about 1½ in. and ligated above and below the point where the transection was to be made in order to prevent the escape of spinal fluid. Following the sectioning, which was done with microscopic scissors, the two ends of the cord were observed to draw apart for a distance of ⅛ to ¼ in. The wound was then cleaned and liberally sprinkled with sulphanilamide. Muscles and fascia were approximated with interrupted silk sutures and the incision closed with tension sutures. The surgery was checked by autopsy upon the completion of the observations.

Changes Following Cord Transection

Tonus and electrical resistance.—It is certain that profound changes occur in the musculature of the body following the spinal lesion. Tonus is reduced below the level of the transection, resulting in a 'limp quietude of the skeletal muscles' (4, p. 151). Electrical resistance is also affected in a marked way, as is demonstrated by the series of readings taken on three of our animals before the operation, and again on the same animals following the operation.[1]

TABLE I

Electrical Resistance (in Ohms) Before and After Transection of the Spinal Cord in Three Dogs

	Pre-operative Resistance	Post-operative Resistance
No. Readings	73	150
Av.	15,650	1,770
SD	14,400	2,080
$SD_{Av.}$	1,690	1,700
V	92	117
Diff.	13,880	
$SD_{Diff.}$	1,700	
CR	8.16	

Before the lesion, the average of 73 measurements of resistance was 15,680 ohms. Such a value compares favorably with previously reported figures on the electrical resistance of normal dogs, which ranges 'generally between 5,000 and 25,000 ohms with 7,500 to 15,000 representing the general level' (7, p. 197). In contrast to these values, the average of 150 post-operative readings was 1,770 ohms. This is about 11 percent of the pre-operative resistance.

Standard deviations and other statistical data for these measurements are given in Table I. The coefficients of variation (V, Table I) show little difference in relative variability before and after the transection despite the change in average resistance. The critical ratio of 8.16 is nearly three times that required for statistical significance of the difference between the averages.

Consistency of post-operative resistance.—That the general course of the post-operative resistance is low and fairly regular may be seen from Fig. 1, where readings obtained both before and after the transection have been plotted. Each point on the graph is an average of 15 resistance measurements—five for each of the three dogs.[2] The

[1] The resistance readings were obtained through stainless steel electrodes two cm. in diameter which were securely taped to the right-hind foot just above the footpads. The hair was removed from the skin at the point of contact with the electrodes. No more than five readings were taken on any *S* on any single day.

[2] Excepting point 1 of the pre-operative series, which is the average of 13 readings.

time elapsing between successive groups of readings following the surgery was 1–3 days, so that the 10 post-operative points on the graph encompass a period of about three weeks. The intervals between pre-operative groups of readings were one week or longer.

It will be noted from Fig. 1 that the resistance following the transection nowhere approaches the resistance beforehand. Nor is there any special trend or gradual change apparent, but the shift is definitely from one level to another. The minimum value plotted before the operation is 8,200 ohms; the maximum value following the operation is 4,620 ohms.

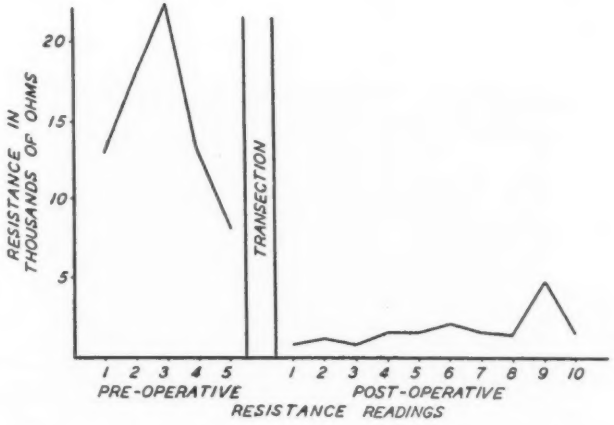

FIG. 1. Electrical resistance in three dogs before and after complete lumbar transection of the spinal cord. Each point on the graph (with the exception of one) is a composite of 15 readings—five for each *S*. The post-operative points are separated by an interval of from 1–3 days and encompass in all a period of about three weeks. The pre-operative points are separated by an interval of one week or longer.

Spinal shock.—Richter (**8**) has shown that the galvanic skin reflex can be obtained from spinal cats only after the spinal reflexes have returned and the animal has completely recovered from spinal shock. He found that the galvanic skin reflex was not fully functional until 10 days or more had elapsed following the transection.

Although all of the reflexes may be absent immediately following transection of the cord, some reappear in the dog about as soon as the effects of the surgical anesthesia have worn off (**5**). We used ether alone, with no supplementary agents, as a means of insuring rapid recovery from the anesthetic. Under these circumstances we were able to obtain many of the reflexes listed in Table II (*vide infra*) in from 2–3 hours after the actual severance of the cord.

TABLE II

REFLEXES OBSERVED IN SPINAL DOGS WITH LUMBAR TRANSECTIONS

	Nature of Reflex	No. of *Ss* in Which Observed	Stimulus
Flexion Reflexes	(*A*) Unilateral flexion	6	Electric shock to homolateral foot
		6	Cold (running water) on homolateral foot
		5	Pinching toes of homolateral foot
	(*B*) Partial bilateral flexion (full flexion in stimulated limb—muscle twitch in contralateral limb)	5	Electric shock to one of the rear feet
	(*C*) Complete bilateral flexion (female dog assumes typical urinating posture)	1	Distension of bladder or act of micturition (in female animal)
	(*D*) Digital flexion	5	Palpation above paw
		5	Palpation of plantar surface of foot
Extension Reflexes	(*E*) Crossed-extension	5	Manual flexing or manipulation of contralateral limb
		5	Electric shock to contralateral limb
		1	Spontaneous (?) flexion of contralateral limb
	(*F*) Direct unilateral extension	4	Pressure on hind paw while limb is flexed
	(*G*) Bilateral extension (animal stands unaided)	6	Rectal pressure
		5	Stimulation of anus with stiff brush
		5	Undefined external manipulation of caudal region
Other Reflexes (sometimes including flexion and extension)	(*H*) Micturition	5	Distension of bladder
		6	Squeezing of lower abdomen
	(*I*) Defecation	6	Rectal pressure
		4	Stimulation of anus with stiff brush
		5	Squeezing of lower abdomen
	(*J*) Erection of tail as in defecation (or urination for female)	3	Distension of rectum or of bladder (in female). Stimulation of anus with stiff brush
	(*K*) Assuming of complete defecating posture of a normal animal, including bending of trunk, erection of tail and bilateral extension of 2 hind limbs (standing)	2	Rectal pressure produced by act of defecating
	(*L*) Continuous tremor of muscles of hind leg	1	Stimulus unknown

If the functioning of galvanic, vasomotor, or other unobserved reflexes was not complete when the post-operative readings of resistance were begun, but returned gradually during the following three weeks—even this produced no alteration in the level of post-operative resistance (*cf.* Fig. 1). The condition of spinal shock, whether abruptly or gradually terminated, probably had no effect, therefore, upon the present electrical measurements.

Responses Observed

In spite of far-reaching changes in the internal condition of the body as indicated by these factors, there are nevertheless many responses similar to those of normal animals which can be elicited in

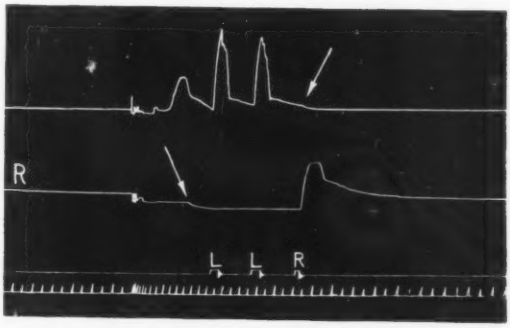

Fig. 2. Kymographic tracings of several responses in a lumbo-spinal dog. The top line, *L*, is the record of movement of the left-hind limb, and the line second from the top is the record of movement of the right-hind limb. The line third from the top is the signal line for electric-shock stimuli delivered to either of the feet, and the bottom line gives time in units of .2 sec.

Spontaneous flexion of the left-rear leg is shown toward the left of the record. When the left leg is extended or depressed, the right is also extended (left-hand arrow).

Flexion reflexes of both right and left legs are produced by the stimuli *LL* and *R*. The two *L*'s represent a.c. electric shocks to the left foot, while *R*, although recorded on the same line, represents a d.c. shock to the right foot.

The crossed extension response is in evidence at the point marked by the right-hand arrow, where the extension of the left leg accompanies the flexion of the right.

the chronic lumbo-spinal dog. A few complex movements, in fact, occur with such precision and coordination that they are not distinguishable from those of the intact animal.

Several reactions of which the low spinal dog is capable are illustrated in the kymographic record reproduced in Fig. 2. The top line, *L*, is the tracing of the movements made by the left-hind foot, and the line second from the top, *R*, is the record of movement of the right-hind foot. The line third from the top is the stimulus line. Letters *L L* on this line indicate a.c. electric shocks delivered

to the left-rear foot, and the letter *R on the same line* indicates the presentation of a d.c. electric shock to the right-rear foot. Time is in units of .2 sec.

Before the occurrence of the first of the electric shocks, this preparation was making spontaneous movements of the hind feet. The left foot was raised while the right was depressed. The right foot was further depressed at the point indicated by the left-hand arrow. By a fortunate coincidence, the kymograph had been started just before the animal made "a step." The result is a graphic recording of the "walking movements" reported by Sherrington (**10**, **11**).

The electric shocks *L L* and *R* may then be seen to produce flexion reflexes in the left and right-hind feet respectively.

The crossed extension reflex is also in evidence. The flexing of the left foot to the d.c. shock, *R*, is accompanied by an extension in the unshocked right foot, which is indicated by the right-hand arrow.

Most of the responses which were noted, together with the stimuli which elicited them, are given in Table II.[3] Twelve different reactions are listed in the table, although many of them are necessarily related. The following are perhaps the most extensive and complex of these activities.

Complete bilateral flexion (reflex *C* in Table II).—This response was observed in but one *S*—the only female of the group—but it was so unusual that it deserves special comment. Although the hind quarters of the animal were suspended in a mechanical device for maintaining the organism in its disabled condition (**6**), this preparation lifted both rear feet from the floor and held them up close to her body during the act of micturition. The posture was identical to that of the normal unoperated female while urinating (**1**). Neither the severance of the spinal cord nor the presence of the supporting device seemed in any way to interfere with the completion of the act as a unified whole.

Defecation (reflexes *I*, *J*, and *K* in Table II).—The natural stimulus for this response is distension of the rectum. That this (and other stimuli) can elicit an elaborate series of movements involving most of the body in lumbo-spinal animals—quite as if they were unoperated—is hardly what one would expect. According to our best observations, *a definite coordination appeared to exist between the parts of the organism above and below the level of the lesion*, so that the entire response of curving the trunk, erecting the tail, and standing upon the hind feet (reflex *K*) was indistinguishable from similar behavior in the intact animal.

[3] The patellar reflex was also easily elicited by a tap on the patellar tendon, although this response has not been included in Table II.

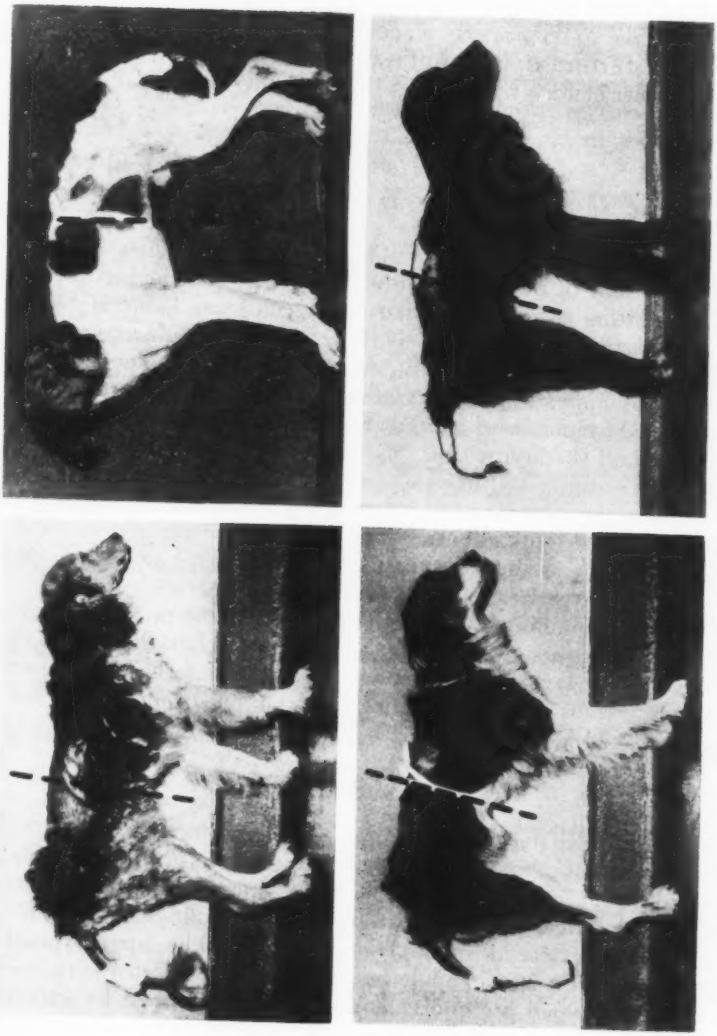

FIG. 3. Momentary standing of chronic spinal dogs completely transected between the first and the third lumbar roots. The broken lines show the location of the lesion, and mark off roughly the 'paralyzed' portion of the body. The photographs were taken from one to three weeks following the transection.

Standing (reflex *G*, Table II).—The powerful bilateral extension of the hind legs permits the animal to stand unaided for periods up to nearly a minute in length. The standing is not a stable reaction, and the feet have to be properly placed so that the animal will remain balanced. Nevertheless, the result is striking, as can be observed from the photographs in Fig. 3.

Discussion

These three sorts of reflexes seem to be intimately related to the process of evacuation—or at least to those body parts having especially to do with evacuation. The bilateral extension itself is perhaps but a part of the larger act of defecating; and the laboratory method of eliciting this response, it will be seen from Table II, is by tactual stimulation of the anus. If there exists a genuine coordination between the parts of the body above and below the level of the transection—as appears from the behavior itself—this coordination may take place by means of afferent fibres which follow sympathetic pathways around the lesion.

Another possibility—although one which is similar—is that the ends of motor fibres from roots below the transection overlap with sensory fibres from roots above. This differs from the first method in that it does not assume connections through large nerve trunks which circumvent the lesion.

Still a third possibility is that the contraction of muscles below the level of the lesion mechanically pulls or stretches the skin and muscles above the level of the lesion. As a result of these tensions, the anterior tissues initiate proprioceptive impulses in their own right (**3**).

Summary

Dogs whose spinal cords are completely sectioned between the first and the third lumbar roots immediately undergo profound bodily changes below the level of the lesion. Not only is muscular tonus reduced but electrical resistance drops to nearly one-tenth its preoperative value, where it remains indefinitely. The lumbo-spinal preparation is nevertheless capable of complex and extensive movements, many of which are equivalent to those performed by intact animals. In addition to localized reflexes, these include the assumption of the complete posture for defecation and for micturition (in the female), as well as momentary standing without any support or aid. The most complex behavior apparently involves coordination between parts of the body above and below the level of the lesion.

If this coordination is not an artifact, it may take place in any of the following ways:

1. By means of afferent fibres through autonomic pathways which circumvent the transection.

2. By the overlapping of the ends of motor fibres from centers below the transection with the ends of proprioceptive fibres from centers above the transection. Although similar to the first method, this possibility does not assume connections through large nerve trunks which go around the lesion.

3. By mechanical pulling or stretching of the skin and muscles above the level of the transection, as a result of muscular activity below the transection. Proprioceptive impulses would be initiated directly in the non-active tissues cephalad to the lesion as a result of these tensions.

(Manuscript received January 2, 1946)

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THE RELATION OF RESPIRATION AND REFLEX WINKING RATES TO MUSCULAR TENSION DURING MOTOR LEARNING *

BY C. W. TELFORD AND ARTHUR STORLIE

University of North Dakota

In 1942 (11) we published data which showed that, in a rather difficult mirror-drawing-learning problem, muscular tension in the active hand decreased for the first 20 trials and then increased regularly to the end of the learning (100 trials). The tension curve thus obtained was 'U' shaped. At that time, we erroneously assumed that these findings were original with us. It seems, however, that Daniel (3) had previously obtained similar results when studying maze learning.

In our 1942 study it was suggested that the initial decline in tension was a part of the relaxation of the initially high generalized bodily tension, and that the subsequent increase in finger pressure represented a differential localization of tension in the muscle groups specifically involved in the tracing. As we had no indices of general tension, it was not possible for us to test the hypothesis at that time.

In the present study we have repeated our earlier work, taking simultaneous records of rates of respiration and reflex winking. It was thought that these additional measures might possibly reflect changes in general bodily tension.

Procedure

The learning problem and methods of recording time, errors, and muscular tension were all the same as in our earlier study, to which the interested reader is referred for further details (11). Rate of respiration was recorded by means of a pneumograph fastened around the chest. Rate of winking was likewise mechanically recorded by means of a spectacle arrangement as described in an earlier study (9).

Nineteen *Ss* completed the learning series of 100 trials. The *Ss* were students enrolled in psychology at the University of North Dakota during the summer of 1942.

Results

Fig. 1 summarizes the results of the present study. The data represent average values for the entire group of 19 *Ss*.

* The data of the present study are taken from the unpublished Master's Thesis of the junior author on file in the library of the University of North Dakota.

The time, error, and tension curves are practically identical in shape to those obtained in our earlier study. The time and error curves are typical of learning of this sort. The tension graph is again 'U' shaped. The initial tension is high. It then drops regularly to the 20th trial and thereafter increases to the 95th trial. There is a slight, but not significant, drop on the last trial.

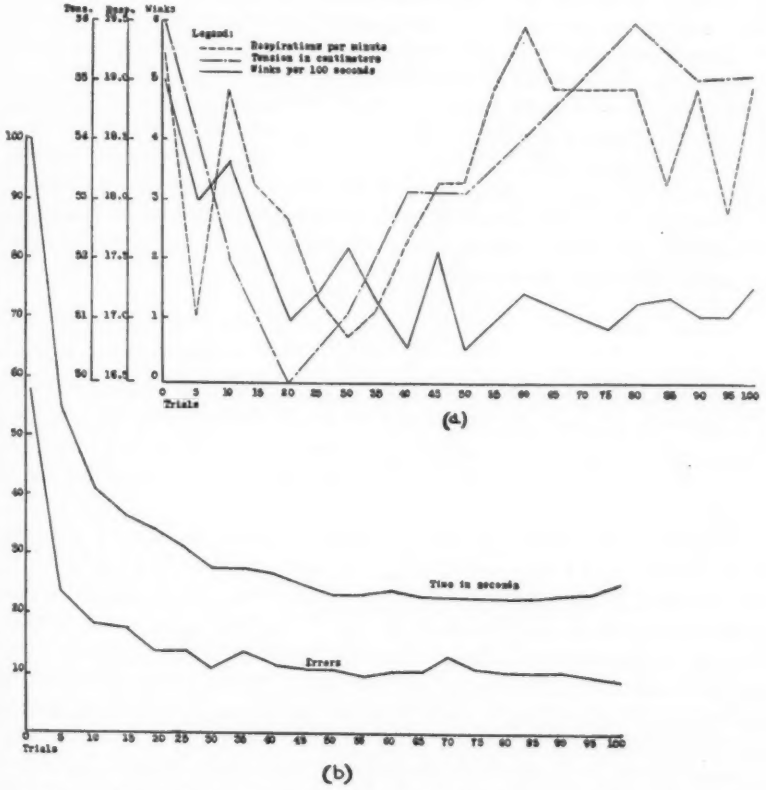

FIG. 1. Curves of tension, respiration, eye-winks, time and errors in mirror drawing. Curves are based on group averages for 19 *Ss*.

The graph of rate of respiration roughly parallels the tension curve, while that of reflex winking follows fairly closely the curves of time and errors. The respiration rate is exceedingly variable from trial to trial; even the group curve shows marked irregularities. Respiration rate correlates .84 ± .01 with the degree of muscular tension. The correlations of respiration rate with the other variables

are around zero. This would be expected from the shapes of the respective curves.

The curve of winking rate, like respiration, is extremely variable, but the general trend is toward a decrease in rate of winking as the learning progresses. Rate of winking (winks per sec.) correlates .59 ± .04 with errors per trial and .63 ± .04 with time (sec. per trial). If, instead of winks per sec., total winks per trial are correlated with time and errors per trial, we obtain values of .89 ± .01 for each.

It was thought that the error data might be more meaningful if reduced to an *error rate* comparable to winking rate. Consequently, we converted the error score to *errors per sec.* and correlated these values with winks per sec. This reduced the correlation between the two to .27 ± .07. The error rate or number of errors per sec. was found to remain practically constant for the entire 100 trials. It is obvious from the shape of our curves that ordinary correlational techniques are hardly applicable to the data, but they are presented for what they may be worth.

Discussion

Is rate of reflex winking an index of general bodily tension? This question has apparently never been attacked directly and the indirect evidence bearing on it is conflicting. Most of the related studies have been primarily concerned with rate of winking as an index of 'ease of reading.'

Luckiesh and Moss (5) report that increases in rate of winking result from: (1) an hour of reading, (2) prolonged work at a difficult, visual task, (3) a decrease in the size of type read, (4) the introduction of glare sources in the visual field, (5) the introduction of a lens to produce a refractive error, and (6) a decrease in illumination. They conclude that rate of winking depends upon the duration and severity of the specific visual task. These authors have used winking rate as an index of visual fatigue and difficulty of seeing.

McFarland *et al.* (6) failed to corroborate the findings of Luckiesh and Moss as to the effect of level of illumination on rate of winking. Some of their Ss showed increases and some decreases with diminishing illumination. They state, "A high blink-rate need mean neither an increase in fatigue, nor an increase in difficulty of seeing. It may, for instance, be an anticipatory protective action. The eyes' indulgence in the normal function may simply enable them to perform their tasks more efficiently. In our opinion, *the normal functioning of vision requires blinking in order to prevent the occurrences of strain. Failure to blink facilitates strain which in turn requires blinking to*

relieve the strain" (**6**, p. 85). These authors go on to show that when *Ss* were instructed to 'blink in a manner to produce relaxation' (**6**, p. 87), the onset of visual fatigue was delayed. Voluntary relaxed blinking proved to be an aid to vision.

The essential difference between the contentions of these two groups of workers is not very clear. Since conditions conducive to strain require additional winking in order to prevent such strain from developing, it would seem that a positive relationship would be found between ease of seeing and winking rate, according to McFarland *et al.*, just as the actual strains are thought to produce increased winking, according to Luckiesh and Moss. In other words, whether winking is a protective device to prevent strain or the result of strains already present, it should correlate positively with 'ease of seeing.'

In reading the discussions of these two groups of workers (Moss and Luckiesh, and McFarland *et al.*), it seems that they are using the terms 'strains' and 'tensions' in two different ways. At times they use these terms to refer to fatigue, strains, and tensions in the visual apparatus proper. At other times they have reference to generalized bodily strains and tensions. For example, Luckiesh and Moss state that "A glare-source within the visual field augments the development of nervous muscular tension incident to the performance of a critical visual task" (**5**, p. 227); also, "these data reveal an extremely close correlation between eyelid reflex and nervous muscular tension" (**5**, p. 230). These quotations suggest that the authors conceive of the difficult visual task as inducing generalized neuromuscular tension. This in turn increases the irritability of all reflex activities, including the wink-reflex. If this is correct, the tensions mentioned are not specific ocular tensions.

On the other hand, the tension to which McFarland *et al.* (**6**) refer seems to be more specific in its nature. When they say that "the normal functioning of vision requires blinking to prevent the occurrence of strain" they apparently have in mind specific ocular tensions.

Arnold (**1**) seems to have been the first to emphasize the distinction between these two types of tension. She calls them 'effort or voluntary or specific tension' which seems to be localized in the working organ, and 'involuntary or diffuse or general' tension which is widespread in its nature. This author finds the first (specific tension) to be directly related to performance, the second (general tension) to be inversely related. She considers tension in the performing hand to be purely specific or effort tension, while that of other parts of the body is general or diffuse. We have considered our tension curves to represent both.

We are immediately interested in the rate of winking as a possible index of diffuse or general tension. Our observed changes in rate of

winking can hardly be the result of specific ocular tensions, since mirror drawing as a visual task is not very exacting and remains more or less constant from the beginning to the end of the learning. What are some of the factors that influence winking rate besides those already mentioned?

Reading retards the normal rate of winking (7, 9, 10). This is probably due to the nature of reading as a visual task. The eye movements involved in reading partially serve the same function as winking. Winking also interferes with the process of reading. These two factors may be responsible for the retardation in rate of winking. Working mental arithmetic increases the rate of winking (10) and all mental activity is thought to involve some degree of muscular tension.

Ponder and Kennedy (8, p. 89) believe that "the rate of blinking is closely related to the mental tension of the subject at the time and . . . the movements constitute a kind of relief mechanism whereby nervous energy, otherwise unutilized, passes into a highly facilitated path."

Luckiesh and Moss (4) found a negative correlation between intensity of illumination and muscular tension as measured by pressure exerted on a key by the finger tips. This fact, in addition to their finding of a negative relationship between illumination and winking rate, supports still further the inference that winking rate is a valid index of general tension.

These facts all suggest that rate of winking is positively related to general muscular tension.

What is the significance of the fact that the tension and respiration curves roughly parallel each other? We started with the notion that rate of respiration might conceivably reflect general bodily tension. We thought that the metabolic products liberated by the effort or localized tension would be too small in extent to affect noticeably the rate of respiration, whereas the more widespread, generalized tensions might do so. If our interpretation of the nature of the tension curve is correct, respiration is influenced by both.

It has been shown that the controls of respiration are multiple. In addition to the oxygen and carbon dioxide controls, we also have reflex effects through the carotid sinus and some possible direct neural controls from muscular contraction itself (2, p. 605). These latter effects seem out of all proportion to the extent of the products of metabolism produced, and may be the ones largely responsible for our observed effects. Perhaps we have in respiration a rather sensitive indicator of muscular tension. We intend to follow up this lead more fully, studying amplitude as well as rate of respiration in further work.

Summary

1. In a fairly difficult mirror-drawing-learning problem, time, errors, tension in the active hand, rate of reflex winking and respiration rate were recorded.

2. The time and error curves were typical of learning of this type.

3. The tension curve was 'U' shaped; that is, it was high at first, then dropped, only to rise again as learning progressed.

4. The respiration graph roughly paralleled the tension curve ($r = .84 \pm .01$).

5. The rate of reflex winking correlated $.59 \pm .04$ with errors and $.63 \pm .04$ with sec. per trial.

6. It is suggested that respiration may vary with localized tension in the hand while rate of reflex winking is correlated with general bodily tension.

(Manuscript received January 18, 1946)

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THE ESSENTIAL STIMULI IN STEREOSCOPIC DEPTH PERCEPTION

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As we continue to examine a pair of stereoscopic drawings, the perception of depth continues to increase until, after a few seconds, it reaches its maximum. During this time the two eyes are roving over the two pictures and fixating homologous details. In doing this the two eyes are constantly changing their degree of convergence, and consequently each moment one eye is moving a little more or a little less than its fellow, or in a reverse direction. The resulting differential stimulation to the muscle sense organs of the right and left eye is contributory, if not necessary, to stereoscopic depth perception. Related to this is the fact that neither of the two component images in the diplopia can be referred to its receiving eye in the absence of differential eye movements (1).

In addition, however, to the dissimilarity of the two retinal images, and to the resulting dissimilarity of kinaesthetic patterns in the muscles of the two eyes, there are other differential stimuli that may contribute to visual depth perception. These are the directional sweep of the image across the retina during eye movements and the presence of various homologous parts of the pictures on which the eyes can anchor following each movement. In the experiment here reported the effect of the presence and absence of these two last mentioned concomitant stimuli is measured.

Procedure

The set-up that was used (*cf.* Fig. 1) contained two similar figures to be fixated and binocularly fused when looked at through a lens assembly. When ready the *S* pressed a switch and received a punctiform flash of light from a neon tube in each monocular field of 1/60 sec. duration. The duration of the light flash was too brief to permit any eye movements to result before the end of the flash. The horizontal distance between the two flashes was sometimes greater than the distance between the fixation points, sometimes less, and sometimes equal to this distance. These three conditions occurred in unpredictable order, and afforded stimulation patterns corresponding to the natural situation in which there is seen a flash of light that is further than the plane of fixation, or nearer, or at the same distance as the fixation plane. Fig. 2 indicates schematically the 10 stimulus patterns used. In each frame of these drawings the centers of the crosses are the fixation points. The dots indicate relatively where the light flashes appear. In the left column of frames the dots are further apart than the fixation points. In the center column they are the same distance apart. In the right column they are less far apart than the fixation points. If both the crosses and dots as shown in the diagram were to be viewed through a stereoscope, the dots in the left column would appear to be further away than the crosses, the

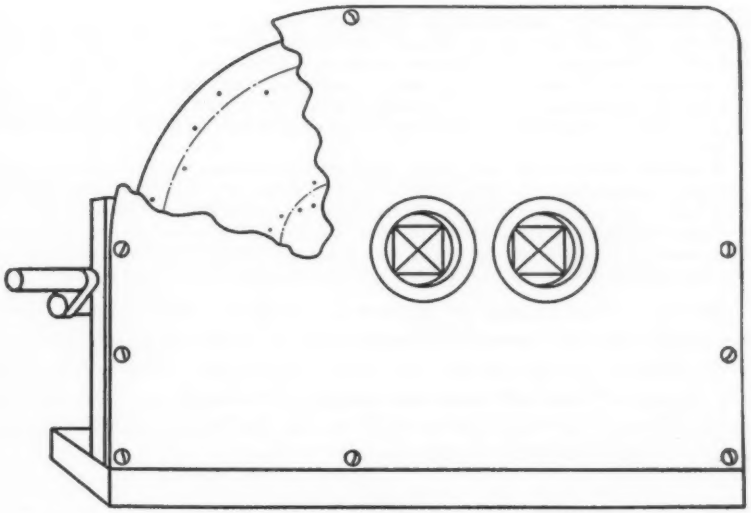

FIG. 1. The apparatus afforded two similar fixation patterns (diagonals within squares within circles) drawn on paper behind which the two stimulation flashes appeared. The position of the flashes was determined by the position of holes drilled in a thin brass disc that lay between a neon tube and the paper. One complete turn of the crank moved the disc through 12 degrees and locked it in place. This permitted a series of 30 stimulations in randomized order.

dots in the middle column would appear in the plane of the crosses and the dots in the right column would appear closer than the crosses. It should be remembered, however, that the *S*s in this experiment had no opportunity to bring the flashes, that correspond to the dots, to bear on corresponding retinal areas, as the flashes lasted only 1/60 sec. The *S* made no eye movements until after the dissimilarity of the right and left eye patterns had disappeared.

Even though the flashes did not sweep across the retinas, and even though they were not binocularly fused following the movements of the eyes, nevertheless the images of the *X* fixation

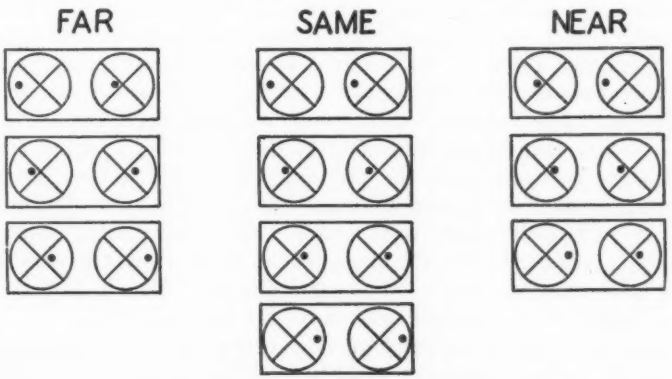

FIG. 2. The 10 stimulus patterns

figures did sweep across the retinas of the moving eyes, and these fixation figures afforded points on which the eyes could again anchor after their excursion, provided these fixation figures remained illuminated. The apparatus permitted two conditions of stimulation. In one of these the light that illuminated the fixation figures remained on throughout the series of stimulations. In the other the illumination ended with the beginning of each flash. Under this latter condition there was, of course, no image sweep and there were no final anchor points for the eyes after their reflex excursion.

Sixteen untrained *S*s were used. Each was given 150 stimulations with the fixation figures constantly illuminated and 150 stimulations in which this illumination was cut off at the beginning of the flash. These conditions were alternated every 30 stimulations. After each stimulation the *S* responded by saying 'near' or 'far' or 'same,' by which he indicated that the flash seemed to him nearer than the fixation plane, or further away, or at the same distance. All *S*s reported that they perceived the simultaneous right and left eye stimulations as a single image.

Results.—The results are shown in Table I. Under each of the two conditions the pooled judgments ($N = 2400$) of all *S*s show an overwhelming preponderance of correct responses. Chi-square with four degrees of freedom is, for continuous illumination, 66.02 and, for illumination of fixation figures only to the beginning of stimulation, 41.51. In each case $P < .000001$.

TABLE I

JUDGMENTS OF FAR, SAME, AND NEAR UNDER EACH CONDITION—TOTALS FOR ALL *S*s

	Light On			Light Off		
	Actually Near	Actually Same	Actually Far	Actually Near	Actually Same	Actually Far
Judged Far.....	318	187	460	283	160	412
Judged Same....	242	156	226	283	146	250
Judged Near....	400	137	274	394	174	298

It is clear that neither the sweep of the image across the retina nor the presence of fixation points available to the eyes after their excursion is necessary for stereoscopic depth perception. The stimulation of non-corresponding retinal areas and the ensuing rectus muscle reflexes alone are sufficient. There is, however, a significant difference between the frequency of correct responses under the two conditions. This is indicated by the corresponding chi-square in each case. When computed from the proportion of correct responses under the two conditions, the difference is 2.7 times the SD of the difference. With continued illumination of the fixation figures, .026 more correct judgments were made. But we cannot with any certainty attribute this to the sweep of the image or to the persistence of available fixation points. The extinguishing of the light may have been a sufficient distraction to account for this difference.

There is a curious assumption that reappears in the literature of this subject, which deserves attention. This assumption seems to be that eye movements do not take place if the period of light stimula-

tion is less than the reaction time. Or the implied assumption may be that after the stimulus has ceased to operate the response cannot be given. Von Kries (2), in commenting on the results which he and Auerback obtained, states that the relative distance of an electric spark and the fixation point may be correctly judged even when, because of the brevity of the observation, *no ocular movements are involved*. Also Werner (3) says: "The theory that the depth of double images depends on the experience of convergence impulses or movements is shown to be false when it is recalled that double images, as Tschermak and Hoejer have demonstrated, are pretty well localized in space during momentary illumination." It is not clear to the present writer just what the inhibitory mechanism is that is supposed to operate here.

Summary.—Stereoscopic depth perception may occur when there is no sweep of the image across the retina and when no subsequent fixation points are available. The double-image stimulation and the resulting rectus reflexes are sufficient.

(Manuscript received January 15, 1946)

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DEVELOPMENT OF SPEECH DURING INFANCY: CURVE OF DIFFERENTIAL PERCENTAGE INDICES

BY HAN PIAO CHEN * AND ORVIS C. IRWIN

In a previous article (4) curves of the development of phoneme types were presented. An index of speech development, devised by one of the authors (1, 3), is the Chen differential percentage index (*DPI*). It is based upon the differences between the relative frequency of the speech sounds in infants and adults. An advantage of this mode of analysis is that it shows the stage of development of infants' speech in terms of the adult. A distribution of the frequencies with which sound types at a given age occur is transmuted into a percentage distribution. These values are then subtracted from the distribution of percentages of frequency of sounds which occur in adult speech. The sum of the percentage differences thereby constitutes a differential percentage index or score. The smaller the infant's score, the closer it will be to the adult standard. The paradigm in Table I hypothetically illustrates the process of calculating the score.

TABLE I

CALCULATION OF DIFFERENTIAL PERCENTAGE SCORE

Phoneme	1	2	3	Others	Total	Score
Adult Standard.....	5%	7%	1%	87%	100%	
Age-level Compared....	20%	35%	10%	35%	100%	
Deviation.....	15	28	9	52		104

The purpose of this article is to present a curve of differential percentages of phonemes in infant vocalization and to indicate its equation. Sex difference also is considered.

The data for the first 30 months of life have been divided into 15 two-month periods. Table II gives the means and the number of infants upon which these values are based. It is in two parts: (*a*) for all data gathered from 95 infants, and (*b*) for the 35 infants of this group which have the most continuous records throughout the two and a half years. Measures of variability will not be treated in this article. The table should be read as follows: for the first two-

* Scholarship from the Committee on Wartime Planning for Chinese Students in the United States.

TABLE II

ALL DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Means	168	159	153	147	139	129	127	118	114	106	98	92	81	78	75
N	62	80	75	64	62	62	57	55	50	41	37	31	32	24	19
Records	125	181	161	170	147	149	127	128	106	84	68	52	51	41	27

MOST CONTINUOUS DATA

Means	166	159	152	149	137	126	125	115	112	105	98	92	83	78	75
N	25	32	32	33	34	35	34	34	34	31	31	27	28	24	19
Records	52	74	71	94	87	91	81	85	74	70	62	48	47	41	27

month period the mean observed *DPI* is 168. During this period, 62 infants were observed and a total of 125 transcriptions of 30 breaths each was recorded.

The equation for the curve based on all available data is $DPI = -6.818\,A + 173.5$; that for the cases with the most continuous data is $DPI = -6.671\,A + 171.5$. In these equations, *DPI* represents the differential percentage index, and *A* the age. Since the constants in the two equation approximate each other, the second will be used in the ensuing analysis.

Fig. 1 shows a curve based on 15 means from the most continuous data. It is derived from the second equation given above. The closed dots represent observed values. The curve is rectilinear, and is negative because the Chen differential percentage index was

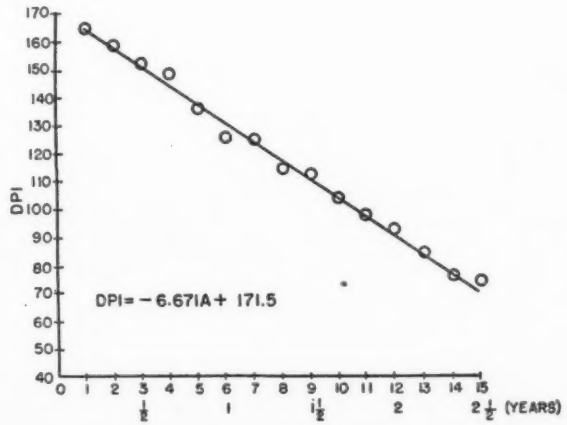

FIG. 1. Differential percentage index as a function of age

designed to give smaller scores with increasing age. The chi-square test of goodness of fit yields a value of 0.916 ($P > .99$).

If the curve is projected to intercept the y axis, then, when $x = 0$, $y = 171.5$. This means that at birth the expected differential percentage score should be 171.5. Chen (2) found that 45 infants under 10 days of age yielded a mean score of 171.2, a value quite consistent with the expected score.

Table III gives the observed means for boys and girls in the group containing the most continuous data.

TABLE III

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Boys	167	158	152	151	140	129	127	115	119	112	100	92	83	85	76
N	13	16	16	17	18	18	18	17	17	16	17	16	16	13	10
Records	27	35	37	53	48	52	47	46	42	37	35	29	32	20	15
Girls	165	160	152	146	133	123	123	114	111	99	95	93	84	70	75
N	12	16	16	16	16	17	16	17	17	15	14	11	12	11	9
Records	25	39	34	41	39	39	34	39	32	33	27	19	15	21	12

The equations derived from these values are $DPI = -6.095\,A + 169.1$ for boys, and $DPI = -6.796\,A + 170.6$ for girls. The curves appear in Fig. 2. The curve shows that the sexes have about the same initial score, and that girls have a tendency to approach the adult level at a slightly faster rate than boys. The differences, owever, are not statistically significant.

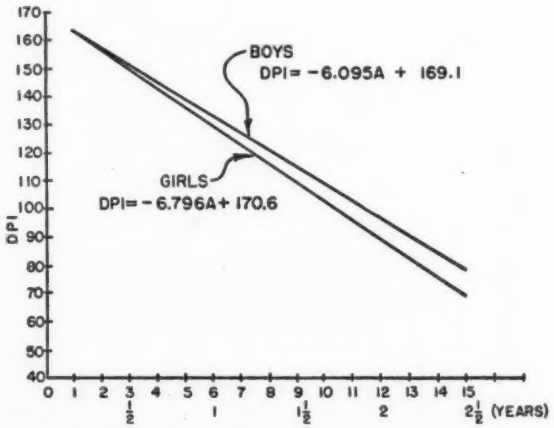

FIG. 2. Sex differences in D. P. index

Summary

A differential percentage index (*DPI*) has been devised, which yields a score based upon the difference between the relative frequency of speech sounds in infants and adults. When this method of analysis is applied to speech sound data collected on 95 infants the resulting equation is $DPI = -6.818\ A + 173.5$. When the data for the most continuously observed infants are plotted according to this method the equation is $DPI = -6.671\ A + 171.5$. The curves are rectilinear in contrast to the curves previously reported. Curves for sex differences are presented which indicate that girls are somewhat advanced over boys in the frequency of use of speech sound elements. The equation for boys is $DPI = -6.095\ A + 169.1$, for girls it is $DPI = -6.796\ A + 170.6$. Sex differences, however, are not statistically significant.

(Manuscript received December 26, 1945)

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BODY SWAY AND VISION

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As is well known, the equilibrium of the human body is determined by a number of complex and interrelated factors, nervous, muscular, and sensory, and is modified by various pathological conditions. Discussions of these factors have been published by Camis (1), Griffith (4), Purves-Stewart (6), Obersteiner (5), Fulton (3), and others; and review of experimental work has been made in an earlier publication by the present writer (2).

This study concerns itself with the problems of how much body sway is affected by various visual conditions: eyes open vs. eyes closed, blindness, experimental distortion of vision, experimental blinding of normal-seeing students, observation of objects, including those that were still, moving, and leaning, no visual fixation vs. fixation of near and distant objects. All experiments were ataxiametric with the exception of one. The latter was ataxiagraphic and a repetition of an earlier experiment which studied the differences of centers of equilibrium with eyes open versus eyes closed.

Apparatus

The apparatus used was the author's ataxiameter already described (2).

Subjects

With the exception of the blind students at the State School for the blind, nearly all *Ss* were students at the University of Georgia, selected at random. All *Ss* acted in both the control and experimental series of each experiment, thus eliminating differences that might be caused by age, height, weight, etc.

Procedure

All trials were for one min., *Ss* being measured for sway front, back, right and left, the sum of the four measurements being used for statistical purposes. At the beginning of each trial, the riders were set at zero; at the end of one min., the sway was read in mm. The order of trials was varied to eliminate possible effects of practice. Trials disturbed by distractions, failure of *Ss* to follow instructions, etc., were stopped and repeated.

Instructions

Standard instructions were as follows: "Stand as steadily as you can with eyes open (or closed), with hands at your sides and toes and heels together."

Results

Although height and weight have been kept constant in the following experiments by the use of the same *Ss* for control and experimental trials, it may be noted that, as already indicated by the present author (**2**) and by Travis (**7**), no significant correlations were found between body sway (static equilibrium) and either height or weight.

Experiment 1

The Blind

Subjects.—There were 72 inmates, aged 5–36 years, 41 males and 31 females, measured for body sway at the State School for the Blind. Degrees of blindness were not determined, but most of the inmates had some amount of vision.

Results.—Results of measurements appear in Table I. Hardly any significant results appear except in the light of the contrast with all other groups. All other groups, feebleminded, insane, deaf, normal, etc., sway on the average more with eyes closed. In the

TABLE I

Body Sway in the Blind

72 *Ss*	Mean	Median	SD	σ_m
Open	225.4	184.3	159.9	18.82
Closed	208.7	175.0	121.8	14.35

CR 1–2 = 0.08.

case of the 72 blind *Ss*, sway on the average was eight percent less with eyes closed. In the case of normal-seeing *Ss*, it is about 50 percent greater with eyes closed.

The difference in the case of the blind is apparent from another point of view. Of the 72 blind, 48.6 percent swayed more with eyes open. Also, of the blind who swayed more with eyes open, the average increase of sway was 46.1 percent. In no other groups have any large numbers been found who sway more with eyes open. In groups totaling 1062 normal *Ss* (college students), the percent of those swaying more with eyes open was 9.7; and of 89 *Ss* aged 30–70 years, the percent was 14.9.

Experiment 2

Normal Ss Experimentally Blinded

The finding that blind students at the School for the Blind swayed on the average more with eyes open, and that nearly half of them

did so, led to further study of the relation of blindness to body equilibrium.

Subjects.—Two experiments were made with 100 unselected college students, cadets in U. S. Army Signal Corps, and instructors in Psychology, aged 18–57 years. It is to be noted that the oldest *S*s did not sway as much as many of the younger *S*s.

Procedure.—The first 50 *S*s wore lenses that distorted vision (plus 5 diopters); the other 50 trials were made with *S*s wearing the same glasses, but with vision further disturbed by the addition of paste and ink on the lenses. In the second experiment the *S*s could just distinguish a person standing before a window, could not recognize him, but could tell when he raised an arm. This condition was made as nearly as possible to equal the vision of the blind man who was a *S* in the next experiment to be reported.

Results.—Statistical results of these experiments are shown in Table II. Considering the averages and the critical ratios, it is clear that greatly distorting vision by lenses is accompanied by increased sway of 36.36 mm. as indicated by arithmetic means, and a critical ratio of 2.9, the difference according to the medians being 52.9 mm.

TABLE II

BODY SWAY AS MODIFIED BY EXPERIMENTAL BLINDING

50 *S*s	Mean	Median	SD	σ_m
Open	129.48	104.0	69.6	9.85
Closed	247.64	252.5	91.2	12.9
Lenses	165.84	156.9	67.4	9.53
CR 1–2 = 7.4; 1–3 = 2.9; 2–3 = 4.9.				
WITH PASTE AND INK ADDED TO THE LENSES				
Open	133.84	138	60.0	8.5
Closed	284.04	274	104.0	14.7
Ink	250.70	218	91.6	12.96
CR 1–2 = 8.8; 1–3 = 7.5; 2–3 = 1.7.				

When still greater interference with vision is made by means of paste and ink on the lenses, the differences are much greater, 118.16 mm., an increase of sway of 87 percent with the very significant critical ratio of 7.5.

Under the four conditions in the experiments, eyes open, vision distorted, vision very considerably reduced, and eyes closed, there is found, in the same order, increased sway with increased statistical significance.

EXPERIMENT 3

Comparison of Two Blind and Five Normal Seeing Ss

Subjects.—Two blind graduates of the School for the Blind, one a man, a student in the Department of Psychology, and the other, a woman who was not a student, agreed to a series of

experiments. They were aged 21 and 22 years, respectively. They were the only blind *Ss* available. Five students working in the Department, two men, aged 20 and 22 years, and three women, aged 19, 20, and 21 years, were used as controls in this experiment. The blind woman could just read newspaper headlines; the blind man could barely see the sidewalk on a bright day and a figure in front of a window and tell when he raised an arm.

Procedure.—Standard procedure was used. Each *S* was given preliminary trials and it was found that the normal, seeing *Ss* swayed more with eyes closed, whereas the two blind *Ss* swayed more on the average with eyes open. Ten regular measurements were then made on each *S* (see Table III).

TABLE III

COMPARATIVE SWAY OF TWO BLIND AND FIVE NORMAL-SEEING *Ss*

Mean	Median	SD	σ_m
Normal controls (50 trials)			
Open 85.8.....	84.5	45.4	6.426
Closed 135.5.....	156.0	72.8	10.295
Blind *Ss* (20 trials)			
Open 304.75.....	322.5	121.1	27.08
Closed 283.75.....	272.5	119.0	26.61

CR 1–2 = 7.4; 3–4 = 1.1; 1–3 = 7.9; 2–4 = 5.2.

Results.—Vision again appears to be of the greatest importance for body steadiness. The results corroborate those found at the State School for the Blind.

This experiment was repeated with goggles (Oxweld No. 16 Lens AA shade medium). Results were similar but with added results from the use of goggles. The man who was extremely blind had sway not significantly changed by the use of the goggles; but the blind woman, who could read newspaper headlines, had much increased sway when wearing the goggles: about 37 percent. With the exception of eyes open and closed for the blind *Ss*, all differences were large and statistically significant.

INTROSPECTIVE REPORTS

Attempts were made to get introspective accounts of experiences of the blind and of the blinded normal *Ss*. These reports repeatedly give the following: "no point of fixation"; "objects greatly blurred"; "fixation of eyes impossible"; "try harder to make distinctions"; "try to see more than I can"; "can't focus and it makes a strain"; "feel completely confused, am keenly aware of trying to see"; "vision blurred, continued fixation makes a big blur"; "shapes distorted, then I focus again and can feel myself sway more." All *Ss* agreed that they tried to see more than they could and that they kept trying to focus; there was inability to focus and continual strain to see. There is the suggestion here that increased effort and strain are highly significant in producing increased sway.

Experiment 4

Experimental Elimination of Eye-movements in the Blind

Subjects.—An attempt was made to run a series of experiments on blind *Ss* using atropine to eliminate eye-movements. Only one blind *S* has been available who was willing to enter the experiment. This was the man used in the other series. One case is wholly inadequate upon which to base conclusions, but it is reported for later confirmation by the present or other experimenters.

Procedure.—One drop of one percent atropine was used in each eye. Control measurements were made before the use of atropine, and measurements followed for two and one-half hours.

Results.—Before the use of atropine, sway was greater with eyes open; after the atropine, the sway changed so that at the end of one hour and a half sway was that of normal *Ss*, namely, greater with eyes closed. This continued for the remainder of the two and one-half hours. The sway with eyes open was reduced about 50 percent.

If similar experiments confirm these results, there will be evidence that decrease or elimination of muscular effort and strain are significant in decrease of body sway.

Experiment 5

Sway and the Reduction of Light in the Dark Room

The dark room was fitted with daylight bulbs and a series of rheostats so that the light could be decreased to complete darkness. A light meter was used to measure the light at the place where the *Ss* were standing.

Subjects.—The *Ss* were 55 men and 45 women, aged 17–25 years, students of the University, who were selected at random.

Procedure.—Four series of measurements were taken, two with full daylight, one with eyes open, the other with eyes closed as controls; two series were then taken, with reduction of light to one candle power, eyes open, the second with complete darkness, eyes open. Standard instructions were given. No time was permitted for visual adaptation, the light being changed from full daylight to one candle power or to complete darkness as the measurements began.

Results.—The increase of sway from the control to the one candle power is 32.8 percent; to complete darkness, 93.7 percent. With this experiment, in which conditions of lighting were strictly controlled, the extreme interference with vision may nearly double body sway. The large critical ratios attest the significance of these results. See Table IV.

Experiment 6

The same series in the darkroom was run with our two blind *Ss*. Each *S* was tested 10 times.

Results.—The critical ratios show little significance as compared with the critical ratios of the normal-seeing *Ss*, all of whose differences with changes of light were significant. The blind *Ss* with eyes open in complete darkness commented on the situation, saying that they were not accustomed to complete darkness and that they made great effort to try to focus the eyes on something. The significance

TABLE IV

SWAY OF NORMAL-SEEING *Ss* IN DAYLIGHT, ONE CANDLE POWER, AND IN COMPLETE DARKNESS

Dark Room Experiment 100 Ss

	Mean	Median	SD	σ_m
Daylight				
Open	104.35	94.0	46.36	4.63
Closed	222.31	211.5	99.8	9.98
One candle power				
Open	138.46	123.5	72.35	7.23
Complete darkness				
Open	202.08	196.0	88.46	8.84

CR 1–3 = 7.4; 1–2 = 10.7; 1–4 = 10.0; 3–4 = 5.6.

lies in the contrast of these results with those of normal-seeing *Ss*. These two experiments check those performed in the other laboratory rooms, and eliminate possible sources of error occurring because of changes of light in rooms with ordinary daylight. See Table V.

TABLE V

SWAY OF TWO BLIND *Ss* IN DAYLIGHT, ONE CANDLE POWER, AND IN COMPLETE DARKNESS

	Mean	Median	SD	σ_m
Daylight				
Open	213.15	218.75	62.5	13.97
Closed	199.60	204.00	54.0	12.07
One candle power				
Open	189.6	177.0	68.0	15.21
Complete darkness				
Open	253.6	241.7	80.5	18.00

CR 1–2 = 0.7; 1–3 = 1.1; 1–4 = 1.8; 3–4 = 2.7.

EXPERIMENT 7

Visual Fixation. Fixation of a Near Spot

Experiments with both blind and normal-seeing *Ss* suggest that effort of fixation, of trying to focus the eyes on some object, tends to increase sway.

Subjects.—In this experiment there were 100 *Ss*, University students selected at random, 63 men, 37 women, aged about 18–25 years (exact ages not available).

Procedure.—The tests were conducted in the darkroom with daylight lighting. A large screen hung about 10 feet in front of the *S*. In the control series, standard instructions were given, and in the experimental series, the same with the addition, "fixate the spot on the screen." The spot was a circular piece of white paper three in. in diameter in the middle of which was a black spot 2½ in. in diameter. In this series the circular paper was pinned to the screen directly in front of *S* at the height of the *S*'s eyes. The screen was of a silver finish and with no spots which could be used as points of fixation.

Results.—The results (see Table VI) show no significant change in steadiness accompanying fixation of the near spot.

TABLE VI

SWAY AND OBSERVATION OF A NEAR FIXATION SPOT

100 *Ss*	Mean	Median	SD	σ_m
No fixation.....	119.8	110.0	59.466	5.97
Fixating spot.....	127.7	114.5	60.704	6.07
CR = 0.9.....				

EXPERIMENT 8

Fixation on a Distant Object

An experiment was also made with a distant object, the letter *L* on a large hotel sign which could easily be seen through the window. The sign was 510 feet from the *S* as determined by engineer's measurements.

Subjects.—These were 120 students chosen at random and children from the playground near the campus and one instructor; there were 62 males and 38 females aged 7 to 60 years.

Procedure.—The standard instructions were given plus the instruction, "Keep your eyes fixed on the letter *L* in the Hotel sign," which could be plainly seen through the window. And for no fixation, the *S* was told, "Look towards the window without fixating on any particular object."

TABLE VII

SWAY AND FIXATION OF A DISTANT OBJECT (510 FEET)

120 *Ss*	Mean	Median	SD	σ_m
No fixation.....	120.24	104.0	74.57	6.9
With fixation.....	115.0	89.0	66.76	6.08
CR = 0.6.				

Results.—Statistical results are found in Table VII. There is the possible suggestion that fixation upon a distant object may help to increase body steadiness, but no satisfactory evidence, with so small a critical ratio. Mean, median, and SD all support the suggestion that there may be some steadying of the body when one fixates a distant object. Another experiment has been planned, but not yet made, requiring no fixation, fixation on a near object, and fixation on a distant object with the same group of *Ss*.

EXPERIMENT 9

Falling Bodies with and without Noise

Four experiments were made in which *Ss* observed falling bodies, one experiment with noise and three without any or as little noise as possible.

Subjects and procedure.—The first experiment with standard procedure, included 75 men and 25 women, aged 17 to 35 years. A large bag filled with sand and two bricks was arranged by means of rope and pulleys to fall from near the ceiling to the floor about 18 feet in front of the *Ss*. The second experiment had the same sized bag which dropped in the same manner but was stopped before it hit the floor. In the latter experiment there was only the barely perceptible noise of the rope and pulleys.

Results.—In the two experiments there were not dissimilar results, namely, an increase in sway of 20 percent when observing the falling bag with a minimum of noise; when observing the bag and hearing the noise of the bag hitting the floor, of 22.4 percent. For the latter the critical ratio was 8.7 and for the experiment without noise, slightly less. The original data for the latter are not available for checking and the critical ratio is therefore not given.

Experiment 10

Falling Pillar

Subjects.—Two experiments were made with 50 *Ss* each, aged 15–36 years, in which a falling pillar was used for the experimental condition.

Procedure.—The pillar was 8 in. × 8½ in. × 8 ft., and painted red. It was erected on a short shaft so that it could be made to fall, but was caught by a rope and strong spring so that it did not hit the floor. It was arranged to fall with a minimum of noise and either sideways or towards the *S*. When erect the pillar was nine feet from the *S* and when falling sideways remained nine feet from the *S;* when falling towards the *S*, the shaft permits the top to come within three feet of the *S*.

Results.—In few cases did the fall of the pillar increase sway more than with eyes closed. With 50 *Ss*, the pillar falling sideways increased sway over the control 15 percent, with a critical ratio of 1.6. When the pillar fell towards the *S*, the average increase of sway was 12 percent, with a critical ratio of 2.6. There is large variability in results with different students. Evidently the sight of a body falling near the *Ss* makes some increase in sway, though not as much as might be expected.

Experiment 11

Observation of a Swinging Pendulum

A large swinging pendulum was hung about 15 feet in front of the *S* as he stood in the ataxiameter. The pendulum made 48 swings per min. In the center of the large bob was a piece of white crayon.

Subjects.—There were 200 *Ss*, 168 males, 32 females, college students, aged 18 to 24 years.

Procedure.—The standard instructions were given for the control series with eyes open and closed. For the series with observation of the swinging pendulum, the instructions were: "Stand as steadily as you can, hands at sides, toes and heels together; follow the white piece of chalk with your eyes." Order of trials was varied to eliminate possible effects of practice or fatigue.

Results.—An earlier experiment showed 12.6 percent of *Ss* swaying more laterally than they did to front and back. In this experiment, while observing the swinging pendulum, 31.5 percent of *Ss* swayed more laterally than when not influenced by the swinging pendulum.

For the 200 *Ss* the mean sway with eyes open was 91.7; with eyes open and observing the swinging pendulum, 163.4, a 78 percent increase.

The right-left sway without the pendulum was 40.1, with it, 83.7, a 109 percent increase in lateral sway when observing the swinging pendulum. The forward-back sway increased from 50.8 to 78.4, or 54.3 percent. Of all *Ss*, 89.5 percent, and of the women, 84.3 percent, swayed more under the influence of the pendulum. See Table VIII.

TABLE VIII

BODY SWAY WITH OBSERVATION OF A SWINGING PENDULUM

200 *Ss*	Mean	Median	SD	σ_m
Open	91.7	85.5	41.9	2.96
Closed	198.8	180.0	105.1	7.43
Pendulum	163.4	151.0	80.2	5.67

CR 1–2 = 13.4; CR 1–3 = 11.2.

EXPERIMENT 12

Leaning Picture

Subjects.—A small and not very significant effect of the observation of a leaning picture was found with 50 *Ss*, unselected college students, aged 17 to 34 years, 31 men and 19 women.

Procedure.—*Ss* observed a framed picture of a country scene, Moore Castle in Ireland, by A. Renldice, 16 × 20 in. in size, placed about 15 feet from the *S*. The control series was with the picture properly hung, the experimental series with the picture leaning to the left at an angle of 15°.

Results.—A few of the *Ss* swayed considerably more under the experimental conditions, but on the whole the difference was not great. The mean for the control series was 115, SD 43.7; for the experimental series, 132.7 SD 60. The difference was 17 mm. with a critical ratio of only 1.7. The lateral sway was increased more than the front-back sway.

EXPERIMENT 13

Eyes Open and Closed When Sitting

Although with the exception of the blind, and a few *Ss* in normal and other groups, sway on the average is considerably and significantly more with eyes closed when *Ss* are in a standing position, the difference does not seem to be significant with eyes closed and with eyes open when in a sitting position on a stool, chair height, but without a back.

Subjects.—There were 100 *Ss*, aged 17 to 35.

Results.—The mean showed a decrease of head sway with eyes closed from 68.82 to 58.05, but a median of 64 with eyes open and 70.25 with eyes closed. Critical ratios are too small to be significant. A few *S*s found it more difficult to sit steadily with eyes closed, but there is no evidence of a general tendency of any significance.

Conclusions

The present study has added somewhat to the knowledge of the extent to which visual factors may affect the sway of the human body. Increase of about 100 percent of sway is found when vision is eliminated by closing the eyes or by decreasing the illumination to the point of complete darkness. Less interference with vision is accompanied by smaller amounts of increased sway. Observation of moving objects has relatively small effects upon sway with the exception of the swinging pendulum, which increased total sway 54 percent and lateral sway 109 percent. Fixation upon near or distant objects that are not moving appears to be accompanied by little, if any, change in body steadiness. In general, it appears that increasing interference with vision is accompanied by relatively increased amounts of sway in the human body.

(Manuscript received January 14, 1946)

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